# Using the Human Error Assessment and Reduction Technique to Predict and Prevent Catheter Associated Urinary Tract Infections

by

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# Abstract

According to the Centers for Disease Control and Prevention (2015), urinary tract infections (UTIs) are the most commonly reported healthcare-associated infection (HAI), of which approximately 75% of infections are attributed to the presence of a urinary catheter. Urinary catheters are commonplace within hospitals as approximately 15-25% of patients receive a urinary catheter during their hospitalization, introducing the risk of a catheter associated urinary tract infection (CAUTI) during their stay (CDC, 2015). In recent years there have been efforts to reduce CAUTI in U.S. hospitals; however, despite these efforts, CAUTI rates indicate the need to continue prevention efforts. Researchers have investigated the use of human reliability analysis (HRA) techniques to predict and prevent CAUTI (Griebel, 2016), and this research builds on that topic by applying the Human Error Assessment and Reduction Technique (HEART) to develop a model for a patient's probability of CAUTI. HEART considers 40 different error-producing conditions (EPCs) present while performing a task, and evaluates the extent to which each EPC affects the probability of an error. This research considers the task of inserting a Foley catheter, where an error in the process could potentially lead to a CAUTI. Significant patient factors that increase a patient's probability of CAUTI (diabetes, female gender, and catheter days) are also considered, along with obesity which is examined from a process reliability perspective. Under the HEART process, human reliability knowledge and the knowledge of eight expert healthcare professionals are combined to evaluate the probability that a patient will acquire a CAUTI.

In addition to predicting the probability of CAUTI, HEART also provides a systematic way to prioritize patient safety improvement efforts by examining the most significant EPCs or process steps. The proposed CAUTI model suggests that 7 of the 26 steps in the catheter

insertion process contribute to 95% of the unreliability of the process. Three of the steps are related to cleaning the patient prior to inserting the catheter, two of the steps are directly related to actually inserting the catheter, and two steps are related to maintaining the collection bag below the patient's bladder. An analysis of the EPCs evaluated also revealed that the most significant factors affecting the process are unfamiliarity, or the possibility of novel events, personal psychological factors, shortage of time, and inexperience. By targeting reliability improvements in these steps and factors, healthcare organizations can have the greatest impact on preventing CAUTI.

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# List of Abbreviations

APOA……………………...……………………………………Assessed Proportion of Affect

CAUTI…………………………….………………Catheter Associated Urinary Tract Infection

EPC…………………………………………………………….....Error Producing Conditions

GRS…………………………………………...…………………...…Graphic Rating Scale

HEART…………………………………...Human Error Assessment and Reduction Technique

HEP……………………………………………………………………Human Error Probability

HRA………………………………………………………..Human Reliability Assessment

NHU……………………………………………………...……Nominal Human Unreliability

# Acknowledgements

I would like to thank my advising professors, Dr. Malgorzata Rys and Dr. Shing Chang for their patient guidance throughout this research, and for ultimately teaching me what it means to be an industrial engineer. I would also like to thank all of the healthcare providers who assisted me in this research. You give so much to your community though it often goes unseen and unrecognized. Thank you for all you do.

# Dedication

I would like to dedicate this work to my family and friends. To my parents, who have supported me unwaveringly throughout this journey, to my brother, Jordan, who always finds the perfect way to make me laugh and remind me not to take life too seriously, and to the wonderful body of friends who have walked with me through this – you mean the world to me and I could not have done it without you. Finally, to the Lord, thank you for this opportunity, may it bring you glory.

# Chapter 1 - Introduction

According to the Centers for Disease Control and Prevention (CDC) (2015), urinary tract infections (UTIs) are the most commonly reported healthcare-associated infection (HAI), of which approximately 75% of infections are attributed to the presence of a urinary catheter. Catheter Associated Urinary Tract Infections (CAUTIs) are urinary tract infections specifically attributed to the presence of a urinary catheter, a “tube inserted into the bladder through the urethra to drain urine” (CDC, 2015). The use of urinary catheters is commonplace within hospitals as approximately 15-25% of patients receive a urinary catheter during their hospitalization, introducing the risk of a catheter associated urinary tract infection (CAUTI) during their stay (CDC, 2015). The consequences of a patient developing a CAUTI include patient discomfort, increased cost for the healthcare organization due to prolonged hospitalization, and in some cases, even death. The last progress report published by the Centers for Disease Prevention and Control (CDC) mentions that despite efforts by U.S. hospitals to reduce the prevalence of CAUTI, there has not been a noticeable difference in CAUTI rates (CDC, 2016). According to Pérez *et al.* (2017), there is not a single strategy adopted by hospitals to combat CAUTI. They suggest that there are many ways in which systems engineers can contribute to the reduction of CAUTI, by providing an “understanding of system factors affecting the development of CAUTI” (pg. 69). Pérez *et al.* (2017) suggest that one approach systems engineers can take to understand the development of CAUTI is through human factors analysis, which can be performed using Human Reliability Assessment (HRA) techniques.

The goal of HRA techniques is to “determine the impact of human error and error recovery on a system” (pg. 157, Kirwan, 1998). This approach was applied by Griebel (2016), who developed a CAUTI prediction model using the HRA technique, Cognitive Reliability and

Error Analysis Method (CREAM), and fuzzy associative memory (FAM) models. In her analysis, Griebel focused on the state of the healthcare environment during catheter insertion, and combined the environmental condition with significant patient factors (gender, diabetes, systemic antibiotics) and urinary catheter days to predict CAUTI. Similarly, the research presented here also focuses on human error to model the development of CAUTI, but with a different HRA technique, the Human Error Assessment and Reduction Technique (HEART) proposed by Williams (1985). In HEART, it is assumed that any given task has a baseline probability of human error, and that this probability is negatively impacted by any potential sources of error (called "Error Producing Conditions", or EPCs). Each step of a process can be analyzed to determine its probability of human error and combined to find the probability of human error for the process. Previous research studies the environmental factors affecting the process overall, and this research expands on previous research by examining the probability of human error in more detail through each step of the catheter insertion process. In addition, a different set of patient factors (gender, diabetes, obesity) were considered in the proposed model as a result of the literature review performed and input from nurse experts.

Using HEART and the knowledge of a panel of nursing experts, a new predictive model for CAUTI was generated by combining the human unreliability probabilities given by HEART with three critical patient factors. The purpose of the proposed model is to give healthcare providers the ability to analyze each step the catheter insertion process from a systems perspective, and to use the model to develop efficient and effective strategies to prevent CAUTI.

## 1.1 Outline of Chapters

A literature review of HEART, its applications in healthcare and other industries, and important CAUTI factors is provided in the next chapter. Chapter 3 discusses the methods used to gather the expert assessments used in HEART, and the methods used to develop the proposed CAUTI probability model. Chapter 4 provides an analysis of the expert assessments collected and the resulting CAUTI models, as well as an analysis of the final proposed model and its potential process improvement applications. Finally, Chapter 5 provides a discussion of the research conclusions and areas of future research.

# Chapter 2 - Literature Review

As mentioned in the introduction, despite many studies on CAUTI, there is still a need to better understand how CAUTI develops and how it can be prevented. The first section in this chapter provides a discussion of CAUTI prediction and prevention approaches, and how this research contributes to those efforts. Section 2.2 provides a detailed description of the central technique applied in this research, the Human Error Assessment and Reduction Technique (HEART). Section 2.3 provides a literature review of HEART applications in healthcare and other industries, and section 2.4 compares the different ways the technique has been applied. Finally, the last section of this chapter provides a literature review of CAUTI, including critical environmental and patient factors that affect the development of CAUTI.

## 2.1 CAUTI Prediction and Prevention Approaches

Researchers have conducted many studies on CAUTI, and recently Pérez *et al.* (2017) reviewed both retrospective and prospective studies performed between 2004 and 2015 in order to determine the systemic studies that have been conducted for CAUTI. They found that the studies were conducted in various contexts and cover a wide range of systemic factors relating to CAUTI. These studies include investigations regarding (all studies as cited by Pérez *et al.*, 2017):

- Catheter use versus postoperative outcomes (Wald *et al.*, 2008)
- Implementation of a reminder system and CAUTI rates (Meddings *et al.*, 2010)
- HAIs in patients of advanced age (Cairns *et al.*, 2011)
- Body mass index versus urinary tract infections (UTIs) (Semins *et al*. 2012)
- Cost of CAUTI for hospitals (Kennedy *et al.*, 2013)
- Risk factors affecting CAUTI development (Lee *et al.*, 2013)
- Development of CAUTI in a non-intensive care unit versus an intensive care unit (Lewis *et al.*, 2013)

- Suitability of catheter use (Tiwari *et al.*, 2012)
- The use of UTI bundles (Titsworth *et al.*, 2012)
- Comparison of best practices to prevent CAUTI (Saint *et al.*, 2013)

All of the aforementioned studies contribute important knowledge related to specific CAUTI risk factors, however, there remains the need to understand CAUTI from a systems perspective. According to Mandelblatt *et al.* (2012), as cited by Pérez *et al.* (2017), healthcare professionals agree that "system analysis and modeling are very important to address increasing healthcare costs, in light of the aging population and emerging technologies" (pg. 74). As a result, it is important for system engineers to be involved in studying CAUTI and developing systemic solutions to reduce the prevalence of CAUTI.

Pérez *et al.* (2017) identify six steps in the "catheter-patient process" in which a patient could possibly acquire a CAUTI: catheterization order, catheter insertion, catheter maintenance, catheterization period, catheter removal order, and catheter removal. They also mention four potential infection risk sources: physician-based, nurse-based, management-based, and device-based. The research presented here aims to provide a systemic perspective on CAUTI development by focusing on the catheter insertion process and a nurse-based infection risk source. The catheter insertion step was studied because it implies a significant amount of interaction between the healthcare provider and the patient, and apart from eliminating catheterization altogether, decreased risk in this step could have the largest impact in reducing the probability of CAUTI.

To the best of my knowledge, there have been CAUTI prediction models developed based on patient risk factors (Platt et al., 1986), however, there is only one other model that predicts CAUTI based on environmental and patient factors (Griebel, 2016). According to Griebel (2016), it is appropriate to apply HRA techniques to the study of CAUTI because healthcare providers are a main potential source of infection. Therefore, her model utilized the Cognitive Reliability and Error Analysis Method (CREAM), and examined different environmental modes together with the following patient factors: gender, duration of catheterization, systemic antibiotics, and diabetes. The model employed fuzzy logic, specifically a fuzzy associative memories model, to predict CAUTI. Similarly, this research contributes to the overall goal of understanding CAUTI systemically through a predictive model based on factors affecting nurses during the catheter insertion process.

## 2.2 Human Error Assessment and Reduction Technique

In the last 30 years, there have been several methods created to quantify the probability of human error in a system. One of these human reliability assessment (HRA) techniques is the Human Error Assessment and Reduction Technique (HEART) proposed by J.C. Williams in 1985.

The first step in HEART involves determining which Error Producing Conditions (EPCs) are possibly relevant to the task being assessed. HEART provides the assessor with a list of EPCs to consider based on extensive research in human reliability. It is assumed that each EPC has a constant effect on human reliability, and that this effect is always reduces human reliability (Cullen *et al.*, 1995). A list of the original EPCs (Williams, 1985) and their maximum effect, or EPC multiplier, given in the technique is shown in Table 2-1, organized from greatest effect to least effect.

Table 2-1: Original HEART EPCs

| | Error-Producing Condition | Maximum Nominal Predicted Effect Factor |
|---|---|---|
| 1. | Unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel | 17 |
| 2. | A shortage of time available for error detection and corrections | 11 |
| 3. | A low signal to noise ratio | 10 |
| 4. | A means of suppressing or over-riding information or features which is too easily accessible | 9 |
| 5. | No means of conveying spatial and functional information to operators in a form which they can readily assimilate | 8 |
| 6. | A mismatch between an operator's model of the world and that imagined by a designer | 8 |
| 7. | No obvious means of reversing an unintended action | 8 |
| 8. | A channel capacity overload, particularly one caused by simultaneous presentation of non-redundant information | 6 |
| 9. | A need to unlearn a technique and apply one which requires the application of an opposing philosophy | 6 |
| 10. | The need to transfer specific knowledge from task to task without loss | 5.5 |
| 11. | Ambiguity in the required performance standards | 5 |
| 12. | A mismatch between perceived and real risk | 4 |
| 13. | Poor, ambiguous or ill-matched system feedback | 4 |
| 14. | No clear direct and timely confirmation of an intended action from the portion of the system over which control is to be exerted | 4 |
| 15. | Operator inexperience (e.g. a newly-qualified tradesman, but not an "expert") | 3 |
| 16. | An impoverished quality of information conveyed by procedures and person/person interaction | 3 |
| 17. | Little or no independent checking or testing of output | 3 |
| 18. | A conflict between immediate and long-term objectives | 2.5 |
| 19. | No diversity of information input for veracity checks | 2.5 |
| 20. | A mismatch between the educational achievement level of an individual and the requirements of the task | 2 |
| 21. | An incentive to use other more dangerous procedures | 2 |
| 22. | Little opportunity to exercise mind and body outside the immediate confines of a job | 1.8 |
| 23. | Unreliable instrumentation (enough that it is noticed) | 1.6 |
| 24. | A need for absolute judgments which are beyond the capabilities or experience of an operator | 1.6 |

Table 2-1: Original HEART EPCs (Continued)

| Error-Producing Condition | Maximum Nominal Predicted Effect Factor |
|---|---|
| 25. Unclear allocation of function and responsibility | 1.6 |
| 26. No obvious way to keep track of progress during an activity | 1.4 |
| 27. A danger that finite physical capabilities will be exceeded | 1.4 |
| 28. Little or no intrinsic meaning in a task | 1.4 |
| 29. High-level emotional stress | 1.3 |
| 30. Evidence of ill-health amongst operatives, especially fever | 1.2 |
| 31. Low workforce morale | 1.2 |
| 32. Inconsistency of meaning of displays and procedures | 1.2 |
| 33. A poor or hostile environment (below 75% of health or life-threatening severity) | 1.15 |
| 34. Prolonged inactivity or highly repetitious cycling of low mental workload tasks | 1.1 (for 1st half-hour)/1.05 (for each hour thereafter) |
| 35. Disruption of normal work-sleep cycles | 1.1 |
| 36. Task pacing caused by the intervention of others | 1.06 |
| 37. Additional team members over and above those necessary to perform task normally and satisfactorily | 1.03 per additional man |
| 38. Age of personnel performing perpetual tasks | 1.02 |

After reviewing approximately 25,000 papers related to human factors research, the creators of HEART decided to revise or add the following EPCs and multipliers (Williams & Bell, 2015):

Table 2-2: New and Revised EPCs

| Error Producing Condition | Status | Maximum Nominal Predicted Effect Factor |
|---|---|---|
| 29. High level emotional stress | Revised | 2 |
| 39. Inconsistency of meaning of displays and procedures | Revised | 3 |
| 35. Disruption of normal work-sleep cycles | Revised | 1.2 per 24 hours sleep lost |
| 33. A poor or hostile environment (below 75% of health or life-threatening severity) | Revised | 2 |
| 37. Additional team members over and above those necessary to perform task normally and satisfactorily | Revised | 1.2 per additional person |
| 38. Age of personnel performing recall, recognition and detection tasks | Revised | 1.16 for every 10 years for ages 25 to 85 years |
| 39. Distraction /Task Interruption | New | 4 |
| 40. Time-of-Day | New | 2.4 from diurnal high arousal to diurnal low arousal |

Therefore, the list of EPCs used in this application include the new EPCs and the revised EPC multipliers.

In the second step in HEART, the assessor identifies the type of task being assessed based on a list of task categories given by the technique, as shown in Table 2-3 (Williams, 1985):

Table 2-3: HEART Task Types

| Generic Task Type | Description | Proposed Nominal Human Unreliability | 5th-95th Percentile Bounds |
|---|---|---|---|
| (A) | Totally unfamiliar, performed at speed with no real idea of likely consequences | 0.55 | 0.35 - 0.97 |
| (B) | Shift or restore system to a new or original state on a single attempt without supervision or procedures | 0.26 | 0.14 - 0.42 |
| (C) | Complex task requiring high level of comprehension and skill | 0.16 | 0.12 - 0.28 |
| (D) | Fairly simple task performed rapidly or given scant attention | 0.09 | 0.06 - 0.13 |
| (E) | Routine, highly-practised, rapid task involving relatively low level of skill | 0.025 | 0.007 - 0.045 |
| (F) | Restore or shift a system to original or new state following procedures, with some checking | 0.003 | 0.0008 - 0.007 |
| (G) | Completely familiar, well-designed, highly-practised, routine task occurring several times per hour, performed to highest possible standards by highly-motivated, highly-trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids | 0.004 | 0.00008 - 0.009 |
| (H) | Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system state | 0.00002 | 0.000006 – 0.009 |
| (M) | Miscellaneous task for which no description can be found | 0.03 | 0.008-0.11 |

Each task type has a corresponding Nominal Human Unreliability (NHU) probability. The effect of relevant EPCs are then applied to the NHU probability using expert opinion to determine the Assessed Proportion of Affect (APOA). In this manner, the assessor or experts decide to what extent each EPC influences human reliability in the system being studied. This is then combined with the EPC multiplier using the following equation (Williams, 1985):

$$Assesed\ effect = (EPC\ Multiplier - 1) \times APOA + 1 \tag{1}$$

where the EPC Multipliers can be found in Tables 2-1 and 2-2, and APOA is in the range of 0 to 1.

Finally, the total assessed nominal likelihood of failure, or human error probability (HEP) is found by multiplying the assessed effect for all relevant EPCs by the NHU for the task type. This is the original HEART method, however, the technique has been adapted in many applications, and the next section discusses applications of HEART in both non-healthcare and healthcare settings.

## 2.3 HEART Applications

Since its development, HEART has been applied in several non-healthcare applications and has more recently been applied in a few different healthcare settings. The next two sections provide a literature review of applications in both contexts.

### 2.3.1 Non-healthcare Applications

Although HEART was designed to be a flexible tool that can be applied in a variety of industries, it has been implemented the most in non-healthcare environments. It has been used especially in the power industry where sensitive, high-risk tasks are a normal part of operations.

In 1997, Kirwan *et al.* conducted an experiment to validate HEART along with two other HRA techniques, the Justification of Human Error Data Information (JHEDI) and Technique for Human Error Rate Prediction (THERP). The experiment involved 30 assessors who had "adequate experience and/or training with the techniques" (pg.18), who each evaluated 30 HEPs with known values based on nuclear and power industry data. Ten assessors were assigned to each technique and after making their estimations, their HEPs were compared to the true HEPs. For HEART, 8 out of the 10 assessments showed a significant correlation between the estimates and true values at the $\alpha = 0.05$ level. Other experimental analyses showed that both experienced and more inexperienced assessors were able to achieve a significant level of correlation. In addition, HEART proved to be moderately pessimistic when compared to the other two techniques. This is good as it is better for the HRA technique to overestimate the probability of human error rather than underestimate it. The analyses also showed that the technique does not always overestimate, therefore validating its general accuracy. It was noted, however, that the assessors were advised to use a maximum of 3 EPCs for each task because using any more would by nature create more pessimistic HEP estimations.

While the overall validity of the technique was good, it did show some limitations or sources of inconsistency. HEART did not appear to be as useful as other techniques for "errors of commission", "slips", or "rule violations". Another limitation or concern, was that in some cases the same HEP was found for the same task, but by using different EPCs. While this could be caused by a slight difference in assessors' understanding of a task, ultimately it implies that strictly using the error reduction guidelines given in HEART may not be the best course of action. Kirwan *et al.* (1997) attributed HEART's inconsistency to generic task type selection and EPC usage. The former is mentioned because the generic task type selected determines the starting HEP value, and thus forms the basis for the assessment. As previously mentioned, the other source of inconsistency is EPC selection which affects HEP estimation and HEP reduction strategies.

Another application of HEART from the energy industry compares HEART to CREAM (Cognitive Reliability and Error Analysis Method) for evaluating human errors in "maintenance procedures on safety venting devices in refueling station hydrogen storage systems" (Castiglia & Giardina, 2013). In this comparison of the two HRA techniques, the researchers chose which EPCs to evaluate based on their knowledge of the process. The EPCs used were: "A means of suppressing or overriding information (EPC 4)", "poor system/human user interface (EPC 6)", "mismatch between perceived and actual risk (EPC 12)", and "little or no independent checking or testing of output (EPC 17)". The authors used fuzzy linguistic variables and their own judgment to determine the APOA of each EPC. Five fuzzy linguistic variables were used: very low, low, medium, high, and very high. Triangular membership functions were developed for each fuzzy variable (see Figure 2-1). After each EPC was rated, the centroid method was employed to determine the value for each APOA. The authors calculated the probability of human error for two steps in the maintenance process and the results showed that the HEART probabilities were higher than those of CREAM (0.0142 and 0.052 vs. 0.017 and 0.018, respectively). The significant difference in the methods was attributed by the author as the human-centered focus of HEART versus the work-context focus of CREAM.

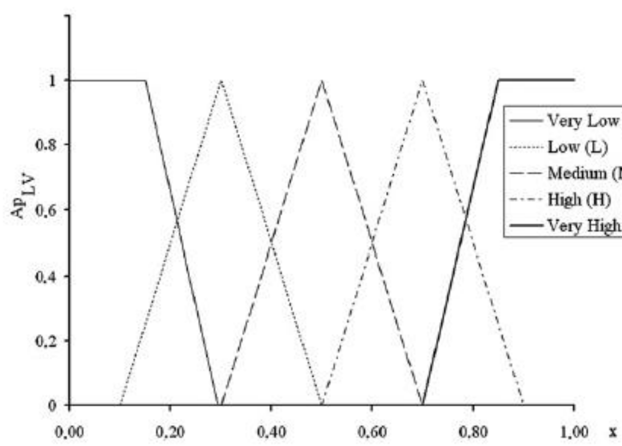


Figure 2-1: Fuzzy Triangle Membership Functions, reproduced from Castiglia and Giardina, 2013

Another application of HEART in maintenance operations looks at the pre and post maintenance activities of a condenser pump (Noroozi *et al.*, 2014). The maintenance operations were divided into 8 activities, each with their respective sub-activities. The HEART method was applied to each of the 46 sub-activities to determine which EPCs had the greatest effect on the human reliability of the maintenance process. Reports from an offshore maintenance team were used to identify relevant EPCs for each sub-activity, and the APOA for each EPC was presumably determined by the engineers conducting the study. After calculating each HEP, the authors connected the probability of error with the consequences of an error. The possible consequences were determined by the authors using information and reports regarding past incidents. These error probabilities and consequences were combined in a risk matrix with different categories of HEP values and consequence severity (i.e. critical, high, medium, low, and warning). This matrix was then used to direct remedial measures in the process.

HEART has recently been applied in the maritime transportation industry. Research performed by Akyuz and Celik (2015) combined HEART with Analytic Hierarchy Process (AHP) methodology to assess the probability of human error for a "cargo tank cleaning operation on-board chemical tankers". As in other HEART applications, the first step taken was to determine which steps or sub-steps in the process to analyze. In this case, there were eight main steps with thirty sub-steps being assessed. Next the researchers sought expert opinions from long-standing personnel to decide which EPCs were relevant to the process. This was done for each sub-step of the cleaning process. After identifying relevant EPCs, the experts were also consulted to define the generic task for each sub-step. Up to this point, the application followed the technique steps prescribed by HEART. When evaluating the APOAs, however, Akyuz and Celik (2015) used AHP methodology to get consistent APOAs across multiple experts. Each expert completed a pair-wise comparison matrix and then the geometric means of the judgments were found to generate one pair-wise comparison matrix. The weights ($w_i$), or APOA, for each EPC was then found using Equation 2,

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \tag{2}$$

where $a_{ij}$ are elements in the i × j pair-wise comparison matrix.

Finally, the HEP for each step and sub-step were found using variations of the original equation in HEART. In this application, the relationship between sub-steps and the overall step were analyzed and calculations were adjusted accordingly. Steps either consisted of sub-steps that behave as a serial system with high or low dependency or a parallel system with high or low dependency. Table 2-4, below, shows the equations used to calculate the HEP for each type of relationship.

Table 2-4: HEP Calculation Equations, reproduced from Akyuz and Celik, 2015

| **System description** | **System sub-task dependency** | **Notation for task HEP** |
|---|---|---|
| Parallel system | High dependency | $HEP_{Task} = Min\{HEP_{Sub-task\ i}\}$ |
| | Low or no dependency | $HEP_{Task} = \prod(HEP_{Sub-task\ i})$ |
| Serial system | High dependency | $HEP_{Task} = Max\{HEP_{Sub-task\ i}\}$ |
| | Low or no dependency | $HEP_{Task} = \sum(HEP_{Sub-task\ i})$ |

The resulting HEPs were organized in a risk matrix to prioritize the remedial measures necessary in the system.

Other applications include assessing the human error probability in the rail industry (Singh & Kumar, 2015), manufacturing maintenance (Aalipour, Ayele, & Barabadi, 2016) and even aviation (Sun *et al.*, 2015). Clearly the technique has been and continues to be accepted for estimating human error probabilities in a variety of settings.

### 2.3.2 Healthcare Applications

There are limited HEART applications in healthcare, and in general, the applications utilize the same steps and modifications as the non-healthcare applications in the previous section.

One HEART application in the medical field studied EPCs related to medical equipment usage in the Intensive Care Unit (ICU) (Drews *et al.*, 2007). This is slightly different than the other applications examined as the authors used HEART in a design context rather than a remedial context. The main goal of the study was to examine the relationship between EPC significance and device criticality. The following EPCs were studied based on the authors' knowledge of the system:

1. Unfamiliarity with a situation (EPC 1)
2. Time pressure in error detection (EPC 2)
3. Low signal-to-noise ratio (EPC 3)
4. Mismatch between an operator's mental model and that imagined by the device designer (EPC6)
5. Impoverished information quality (EPC 16)
6. Ambiguity in performance standards (EPC 11)
7. Disruption in normal work-sleep cycles (EPC 35)
8. Unreliable instrumentation (EPC 23)

To understand the relationship between the EPC significance and device criticality, the authors developed a questionnaire related to the presence of EPCs in the ICU and related to specific devices, and distributed it to 25 ICU nurses. The participating nurses were all at least active registered nurses with at least one year of experience that currently worked in the ICU. The questionnaire consisted of 121 statements that the nurses rated on a scale of 1 to 9. After the questionnaires were completed, the mean score for each question was calculated based on a unidirectional scale. Results of the study showed that in the ICU, the effect of some EPCs varied depending on the criticality of the device in question.

Another application of HEART in the medical field studied the task of "record abnormal blood results" in the radiology treatment process (Chadwick & Fallon, 2012). This task required nurses to enter abnormal blood results into electronic medical records (EMRs) under distracting and time-pressured conditions. A team of three nurses determined which EPCs were relevant to the task based on the list provided in HEART. These EPCs include:

1. A shortage of time available for error detection and correction (EPC 2)
2. No obvious means of reversing an unintended action (EPC 7)
3. Little or no independent checking or testing of output (EPC 17)
4. Task pacing caused by the intervention of others (EPC 36)

Two of the three nurses had 4 years of experience in the participating hospital, the other nurse had 15 months of experience with the participating hospital but 20 years of nursing experience prior. After determining the relevant EPCs, the nurses were given a graphic rating scale (GRS) with the descriptors: negligible, minor, moderate, major, and extreme, to mark their APOA for each EPC. The average APOA was calculated from each GRS. The same team chose the generic task type (in this case Category Task G was chosen) for this analysis. The HEP of the task was calculated using the steps prescribed by HEART and remedial measures were determined based on the EPC percentage contributing to the task HEP.

Most recently, HEART was applied to steps in a robotic surgical Radical Prostatectomy procedure (Trucco, Onofrio, & Galfano, 2017). This study compared the EPCs in HEART to 20 Influencing Factors (IFs) already accepted in the surgical context. There were two critical tasks evaluated in the study, and the two tasks were chosen based on expert opinion and literature. Three fully trained surgeons were given questionnaires to choose relevant IFs for each task. They were also asked to evaluate the percentage of affect for each IF, and estimate the percentage of this affect that was translatable to HEART EPCs. All EPCs except numbers 27, 28, 30, 31, 34, 38 were considered by the assessors (EPCs were excluded on the basis that they were developed for the nuclear industry, and therefore are not suitable for a surgical context). The actual EPCs selected were 2, 3, 5, 7, 8, 10, 12, 18, and 25. In order to calculate the HEP for each task, the average percentage of affect was taken for each IF. Both task were categorized as task type G. After calculating the HEP values, the assessor conducted a sensitivity analysis using reference scenarios and changing factors related to personal conditions, team conditions, and organizational conditions. They found that poor organizational factors had very little effect on the human unreliability rate, however poor personal conditions and poor team conditions had a sizable effect on the human unreliability rate. Finally, the researchers compared HEART's EPCs to the IFs based on three categories: organizational factors, operator factors, and technological factors. The comparison showed the greatest discrepancy for operator factors. The difference was estimated at 16.8%, that is HEART covers the approximately 83.2% of the IFs. As the authors suggest, this shows the need to adapt HEART in order for it to be applied in surgery, but possibly in healthcare in general.

## 2.4 Comparison of HEART Applications

HEART is a versatile HRA technique and, as such, there is considerable variation between its applications. Nevertheless, there are also some similarities between applications regardless of the assessment setting. Most applications started by identifying the steps and sub-steps for the process being analyzed. This information could be gathered from procedural documentation or explained by process experts. Once the process steps were established, the next step was to determine which EPCs were relevant, and assessors either performed this analysis themselves or consulted a team of experts to help identify these EPCs. The latter was the case for both of the healthcare applications. The HEART step with the most differences across applications was estimating the APOA for each EPC. This was accomplished in several different ways, including:

1. Assessor estimations (Kirwan *et al.*, 1997)(Kirwan, 1997)(Noroozi *et al.*, 2014)
2. Expert estimation (Singh & Kumar, 2015)( Aalipour, Ayele, & Barabadi, 2016)(Trucco, Onofrio, & Galfano, 2017)
3. Fuzzy modeling with expert estimation and linguistic variables (Castiglia & Giardina, 2013)(Casamirra, *et al.*, 2009)
4. Graphic rating scale (GRS) with expert estimation (Chadwick & Fallon, 2012)
5. Analytic Hierarchy Process (AHP) with expert estimation (Akyuz & Celik, 2015)

Clearly in most cases the assessor is not familiar enough with the process to estimate the APOA for EPCs, thus experts are consulted to bridge this knowledge gap.

Unfortunately, information regarding EPCs used in each application is fairly scarce. Most of the literature reviewed discusses a few of the EPCs used as examples, but does not explain the reasons why the selected EPCs are chosen for each process step. As with estimating the APOA of each EPC, in many applications the EPCs themselves were determined by experts based on their knowledge of the system.

The most comprehensive EPC information for an application was provided by Akyuz and Celik (2015). Their application assessed the HEP for 30 sub-steps of a cargo tank cleaning process. Figure 2-2 on the next page gives a summary of the EPCs used and how frequently they were considered among all the sub-steps. The graph shows that the two most commonly used EPCs were 1 and 14. It also shows that there was fairly even use of EPCs with large maximum effect (EPCs 1-17, with maximum effect greater than or equal to 3) and EPCs with comparatively small maximum effect (EPCs 18-38, with maximum effect ranging from 1.02 to 2.5).

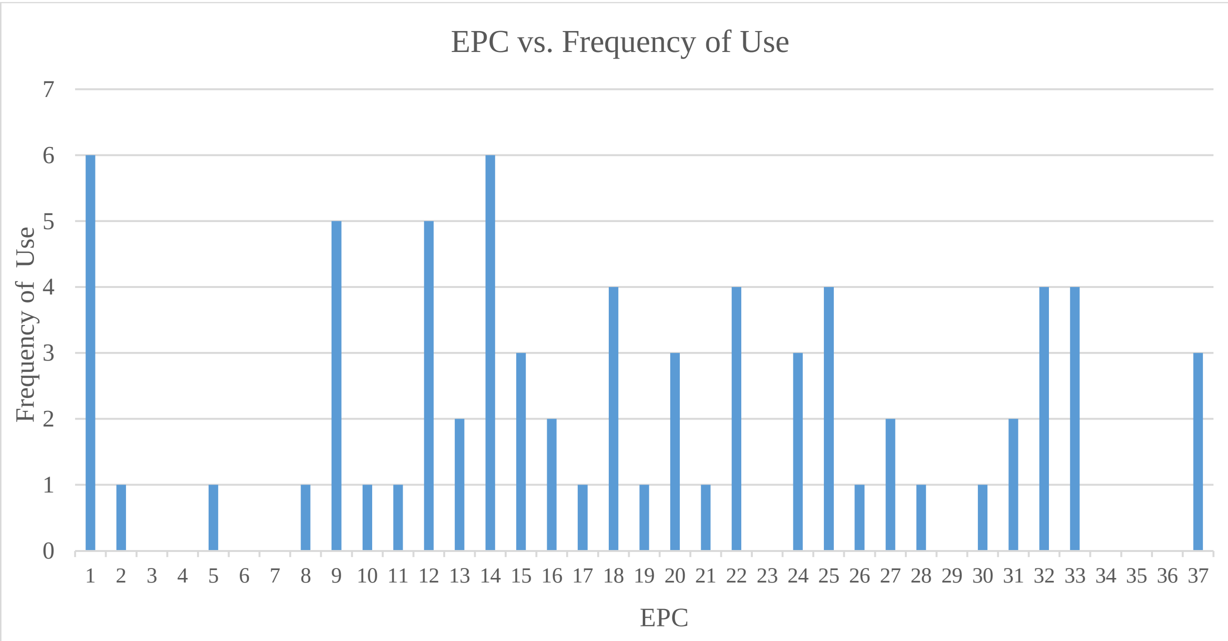


Figure 2-2: EPC vs. Frequency of Use in Cargo Tank Cleaning Process

Finally, after evaluating the relevant EPCs, the assessors assigned a generic task type for process or step. With regards to the generic task type, each application consistently used the generic task types and corresponding NHU values.

## 2.5 Catheter Associated Urinary Tract Infections

A catheter associated urinary tract infection (CAUTI) is a urinary tract infection caused by the presence of an indwelling urinary catheter or Foley catheter. Based on the CDC's definition of a CAUTI, there are three criteria that a patient must meet for an infection to be diagnosed as a CAUTI (NHSN, 2017):

1. An indwelling urinary catheter must be in place for at 2 days before the event (i.e. infection) or removed the day prior to the event.
2. The patient shows one of the following signs and symptoms:

- Fever (>38.0°C)
- Suprapubic tenderness
- Costovertebral angle pain or tenderness
- Urinary urgency
- Urinary frequency
- Dysuria

3. Patient has a urine culture with no more than two species of organisms identified, at least one of which is a bacterium of $\geq 10^5$ CFU/ml.

In general, the presence and manipulation of the catheter introduce an increased risk of bacteria that can cause an infection entering the urinary tract. According to Tambyah, Halvorson, and Maki (1999), there are two principle mechanisms by which organisms enter the bladder:

1. Organisms enter the bladder traveling along the external surface of the catheter from the perineum by way of the mucous film. This typically occurs early, at the time of insertion, but can also develop through prolonged use by way of the mucous film.
2. Organisms gain internal access to the catheter through inadequate drainage closure and contamination of collection bag urine.

According to Trautner and Darouiche (2004), CAUTI is mainly the result of a patient's colonic flora (bacteria) or bacteria from a health worker's hands. They also acknowledge that even though the catheter is placed in a natural orifice (as opposed to a central venous catheter, for example, which is inserted unnaturally through the skin), "the presence of the urinary catheter alters the physiology of the urinary tract and predisposes the individual to infection" (pg. 847). Another possible mechanism suggested to cause infection is excess urine that remains in the bladder. Compared to other devices, such as a central line catheter, where there is regular flow of media through the tube, the media in a urinary catheter is static much of the time.

Of course the most direct way to prevent CAUTI is to eliminate the catheterization of patients, but there are many appropriate reasons for catheterizing a patient, such as monitoring urinary output for obstructions in the urinary tract and postoperative protection. Staff convenience, however, should not be the only reason for catheterization. A study by Tsuchida *et al.* (2006) found that 35% of patients were catheterized unnecessarily. For the remaining patients that do require a catheter for appropriate reasons, best practices have been established in an effort to prevent CAUTI.

In a comparison of best practices of hospitals with the highest CAUTI rates and lowest CAUTI rates, it was found there were higher percentages of improper care practices in hospitals with higher CAUTI rates (Tsuchida *et al.* 2006). These practices include:

1. Clamping the drainage tube (50% vs. 4%, respectively, $p<0.001$)
2. Drainage system disconnected (65% vs. 40%, $p<0.001$)
3. Drainage bag in contact with the floor (36% vs. 6%, $p<0.001$)
4. Drainage bag and tube placed higher than the patient’s bladder (63% vs. 38%, $p<0.001$)
5. No daily cleansing of perineal area (86% vs. 25%, $p<0.001$)

Other general guidelines for prevention are summarized in “How-to-Guide: Prevent Catheter-Associated Urinary Tract Infections”, published by the Institute for Healthcare Improvement (2011), and include:

1. Only use urinary catheters when necessary
2. Maintain aseptic technique when handling the catheter
3. Properly maintain the catheter once inserted
4. Remove the catheter as soon as it is no longer necessary

All of these best practices reflect the concept that CAUTI is mainly caused by introduction of bacteria into the urinary tract through healthcare providers or a patient's own urine.

In addition to poor environmental conditions or practices that can contribute to the development of CAUTI, there are also patient factors (medical characteristics) that have been shown to increase a patient's risk of CAUTI. The two risk factors that were significant across all of the literature surveyed are female gender and urinary catheter days. Maki and Tambyah (2001) summarized four studies and determined the range for relative risk female gender provided by was 2.5 to 3.7 (see Supplemental CAUTI References).

With regards to catheter days, it is often cited that one of the most key factors in preventing CAUTI is removing the catheter as soon as it is no longer essential. According to Tambyah and Maki, as cited in Crouzet *et al.* (2007), "the daily rate of bacteriuria varies from 3% to 10%" (pg.254). This is supported by a comparison the risk of a urinary tract infection in non-catheterized females versus catheterized females, showing that when bacteria are introduced into the bladder, "in the presence of an indwelling urethral catheter, the rate of acquisition of high-level bacteriuria is approximately 5% per day" (Saint & Lipsky, 1999, as cited in Trautner & Darouiche, 2004). Another study suggests that the risk of bacteriuria increases significantly after 1 week of catheterization (Tschida *et al.*, 2006). The observational study conducted by Crouzet *et al.* (2007) suggests the "peak of CAUTI rates" are on days 5 and 6 after catheterization.

One of the risk factors that was not universally found to be significant is diabetes. Platt *et al.* (1986) found diabetes to be a significant risk factor with an OR of 2.3, however, the study by Graves *et al.* (2007) found diabetes to be insignificant. In "Current Opinions in Infectious Diseases", Tambyah and Oon (2012) still hold that diabetes is a significant risk factor for

CAUTI. Recent trends in the prevalence of diabetes also point to the need to consider the impact of diabetes on CAUTI. According to the CDC (2017a), the number of adults with diabetes increased by 43% between 2005 and 2015, from 16.32 to 23.35 million people. In addition, it is estimated that 7.2 million people may have undiagnosed diabetes (CDC, 2017b). Given the considerable increase in the prevalence of diabetes in the U.S., it was included as a risk factor in the proposed CAUTI model, using the relative risk range 2.2 to 2.3 (Maki and Tambyah, 2001).

The other patient factor considered was obesity. Based on discussions with healthcare providers, for obese patients there are added complexities in the catheter insertion process. Like diabetes, obesity is also an increasingly prevalent health condition in the U.S. As of 2014, more than 1 in 3 adults are obese, and it is recognized that one of the complications of obesity is diabetes (Ogden *et al.*, 2015). According to the National Diabetes Statistics Report (CDC, 2017b), 61.3% of adults with diagnosed diabetes are obese. Therefore, obesity was also considered in the proposed model, but as a patient factor affecting the reliability of the catheter insertion process. This is discussed in more detail in chapter 3.

# Chapter 3 - Methods

The main objective of this research was to develop a predictive model for CAUTI based on the HEART HEP for the catheter insertion process and significant patient factors. As mentioned, the two main steps in HEART are determining relevant EPCs and their APOA. This chapter describes the methods used to collect this information, which includes a discussion on which EPCs were evaluated for the process, a description of the expert panel and the questionnaire used to assess the effect of each EPC. Finally, the last section provides a description of how the CAUTI predictive model was developed combining expert opinion with patient risk factors.

## 3.1 Process Steps

The basis of HEART is to evaluate the probability of an error for a task performed based on the factors present while performing the task. Therefore, it was logical to begin by establishing the individual steps composing the urinary catheter insertion process. Based on discussions with healthcare professionals, I determined that there is not a single standard operating procedure for the urinary catheter insertion process, but rather healthcare professionals rely on techniques learned in school and the catheter manufacturer’s recommendations to perform a urinary catheter insertion. Therefore, I used a BARD SURESTEP™ Foley Tray System provided by a local hospital to determine the process steps. This product includes step-by-step instructions on the packaging as well as directions for use inside the kit. This system is standard for both of the major organizations consulted throughout the research. Using the materials provided, 27 steps were identified for the catheter insertion process (see Table A-1 in Appendix A for a list of the steps). These steps were confirmed with healthcare professionals for both accuracy of the steps identified and the correct sequence of steps. This set of steps served as the basis for the individual step analysis, in order to determine the probability of an error at each step and the overall probability of the patient acquiring a CAUTI.

## 3.2 EPC Selection

After determining the process steps being studied, the next step in the HEART process is to define the relevant EPCs for each step. As mentioned in the literature review, there are a total of 40 different EPCs that can be used to categorize the type and severity of the risk factors present when performing a task. Not all 40 EPCs are relevant for each task, and the EPCs that pertain to one task do not necessarily apply to all tasks. Therefore, healthcare professionals were consulted to determine which EPCs they believed were relevant for each step of the catheter insertion process. Initially I reduced the list of EPCs by omitting the EPCs that were considered irrelevant, these EPCs are listed in Table 3-1.

Table 3-1: EPCs Omitted from Analysis

| Error Producing Condition | Maximum Nominal Predicted Effect Factor |
|---|---|
| 5. No means of conveying spatial and functional information to operators in a form which they can readily assimilate | 8 |
| 10. The need to transfer specific knowledge from task to task without loss | 5.5 |
| 19. No diversity of information input for veracity checks | 2.5 |
| 26. No obvious way to keep track of progress during an activity | 1.4 |
| 30. Evidence of ill-health amongst operatives, especially fever | 1.2 |
| 32. Inconsistency of meaning of displays and procedures | 1.2 |
| 33. A poor or hostile environment (below 75% of health or life-threatening severity) | 1.15 |
| 38. Age of personnel performing recall, recognition and detection tasks | 1.16 for every 10 years for ages 25 to 85 years |

EPC 5 was the EPC with the highest nominal multiplier, and it was not considered in this analysis due to an absence of spatial or functional information in this process. The EPC with the next highest nominal multiplier that was not considered was EPC 10. This research assumes that the same healthcare provider that starts the catheter insertion will complete the catheter insertion, and therefore there is no need to transfer information during the process. EPC 19 was omitted from consideration because there is no significant information input in this process, nor is there a significant volume of input that would cause lack of information diversity to affect the process. EPC 26 was determined to be irrelevant because the process progress is guided by the directions for use included in the catheter kit, and because the healthcare provider is the sole initiator for each step of the process. Similarly, EPC 32 was omitted because the kit contains a standard display of the process procedures. EPCs 30 and 33 were omitted because this research assumes that healthcare providers would not be performing a catheter insertion while ill. Finally, EPC 38 was omitted as another EPC (15) would account for differences in age in terms of experience, and that experience is more significant to a healthcare provider's ability to perform recognition and detection tasks.

After determining which EPCs should be considered for this application, a team of 4 registered nurses provided their opinions of which EPCs were relevant for each process step (the nurses were self-divided into 2 groups based on the hospital for which they work – the first group consisted of  a single nurse, an RN with over 20 years of experience currently working as the Supervisor of Infection Prevention, and the second group consisted of 3 RNs, 2 with over 20 years of experience, 1 with 10 years of experience, and all 3 nurses in positions related to patient safety or infection prevention). In addition to the 27 process steps identified previously, a discussion with one of the nurses also raised the issue of added complications in the case that the patient is obese. As mentioned in the literature review, obesity is very prevalent in the U.S. and as a result should be considered in the analysis. Therefore, given a list of potential EPCs and a short description each, the nurses provided their evaluation of relevant EPCs for the 27 process steps and for the process overall if the patient is obese (the obese patient EPCs are captured in the step labeled “OBS”). The results of the evaluations were analyzed to determine the degree to which both parties agreed on the relevant EPCs, and to determine which EPCs would be considered in the next phase of the modified HEART process.

Comparing the two EPC evaluations, there were 16 steps that had at least 1 EPC in common, and 4 steps with at least 2 EPCs in common. The most commonly selected EPC was EPC 15 (operator inexperience), which was selected for all steps on one evaluation, and almost half of steps on the second evaluation. In Evaluation 1, 10 EPCs made up 80% of the EPCs selected overall, where EPCs 29, 35, 36, 37, 39 and 40 are combined under “Personnel or Psychological Stress”, or PPS. This distinction was made because the EPCs included in the PPS factor are all minor EPCs, that is, their respective multipliers are less than 3. Figure 3-1 shows the Pareto chart for Evaluation 1.

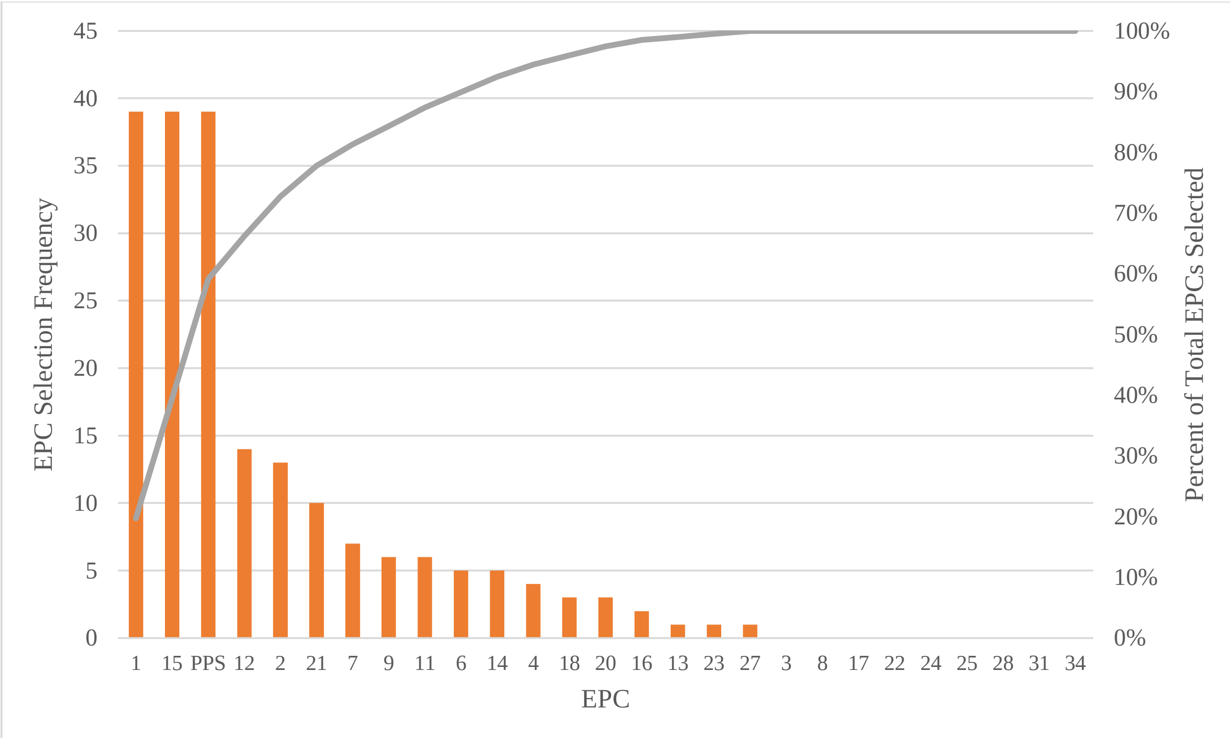


Figure 3-1: Pareto Chart for EPC Evaluation 1

The assesors that completed Evaluation 1 chose the following EPCs as relevant for all process steps:

- Unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel (EPC 1)
- Operator inexperience (e.g. a newly-qualified tradesman, but not an “expert”) (EPC 15)
- High-level emotional stress (EPC 29)
- Disruption of normal work-sleep cycles (EPC 35)
- Task pacing caused by the intervention of others (EPC 36)
- Additional team members over and above those necessary to perform task normally and satisfactorily (EPC 37)
- Distraction/Task Interruption (EPC 39)
- Time-of-Day (EPC 40)

As shown in the Pareto chart, they also emphasized EPC 12, “a mismatch between real and perceived risk”, EPC 2, “a shortage of time for error detection and correction”, and EPC 21, “an incentive to use other more dangerous procedures”. In general, these EPCs focus on the healthcare provider's ability to understand risk, manage personal stress and time, and rely on their experience to perform the catheter insertion in a way that minimizes the risk of infection.

As shown in the Pareto chart, below, the assessor that completed Evaluation 2 focused on different EPCs:

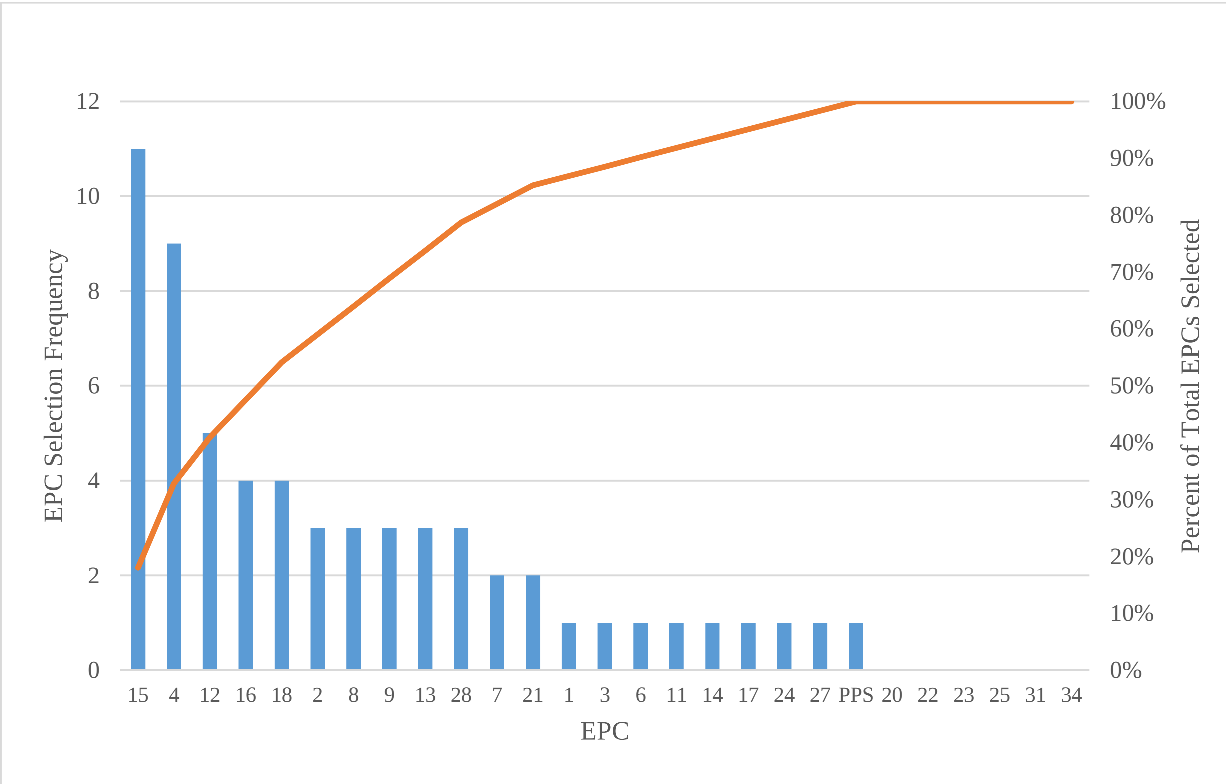


Figure 3-2: Pareto Chart for EPC Evaluation 2

Similar to the other assessors, this assessor chose "operator inexperience" (EPC 15) and "a mismatch between real and perceived risk" (EPC 12) as important factors. In contrast to the other assessors, this assessor more often selected different EPCs such as "a means of suppressing or over-riding information or features which is too easily accessible" (EPC 4), "an impoverished quality of information conveyed by procedures and person/person interaction" (EPC 16), and "a conflict between immediate and long-term objectives" (EPC 18). The selected EPCs show that while this assessor agrees with the importance of risk perception as a factor, this assessor focuses more on factors related to the information exchanged or utilized during the catheter insertion process.

Both of the perspectives provided in the evaluations were valid, therefore all of the EPCs selected for each process step were considered in the next part of HEART. This was primarily done so that assessors would be aware of the EPCs selected by other assessors when evaluating the significance of each EPC. This was also done due to my lack of medical expertise, it was more appropriate to include EPCs that may truly be irrelevant rather than omit EPCs that are deemed irrelevant by assessors with no experience with the process.

Using the EPCs chosen by the process experts, the next step of the HEART process is to evaluate the extent to which each EPC affects the probability of an error occurring in each task. One modification was made before evaluating the APOA of each EPC, however. Because the EPCs comprising the PPS factor are all minor EPCs (i.e. EPCs with a Maximum Nominal Predicted Effect Factor less than 3), they were combined into two newly defined EPCs:

Table 3-2: Minor EPCs Combined

| **New EPC** | **EPCs Included** |
|---|---|
| EPC A – Personal Health/Time Factors | • EPC 29: High-level emotional stress<br>• EPC 35: Disruption of normal work-sleep cycles<br>• EPC 40: Time-of-Day |
| EPC B – Outside Influence Factors | • EPC 36: Task pacing caused by the intervention of others<br>• EPC 37: Additional team members over and above those necessary to perform task normally and satisfactorily |

The minor EPCs were combined based on whether the factors exist when additional personnel are present, or are independent of other personnel. The overall effect of combining the EPCs gives them more weight within the new EPC compared to considering them separately, within a given range.

As explained with Equation 1 in Chapter 2, the assessed effect of each EPC is calculated as:

$$Assessed\ Effect = (EPC\ Multiplier - 1)\ x\ APOA + 1$$

After calculating the assessed affect for each EPC, the values are multiplied together with the NHU for the corresponding task type. Thus, the total multiplier for the effect of the EPCs is the product of all of their assessed affects. The figure below shows the total multiplier derived when the EPCs in EPC A are separate versus combined:

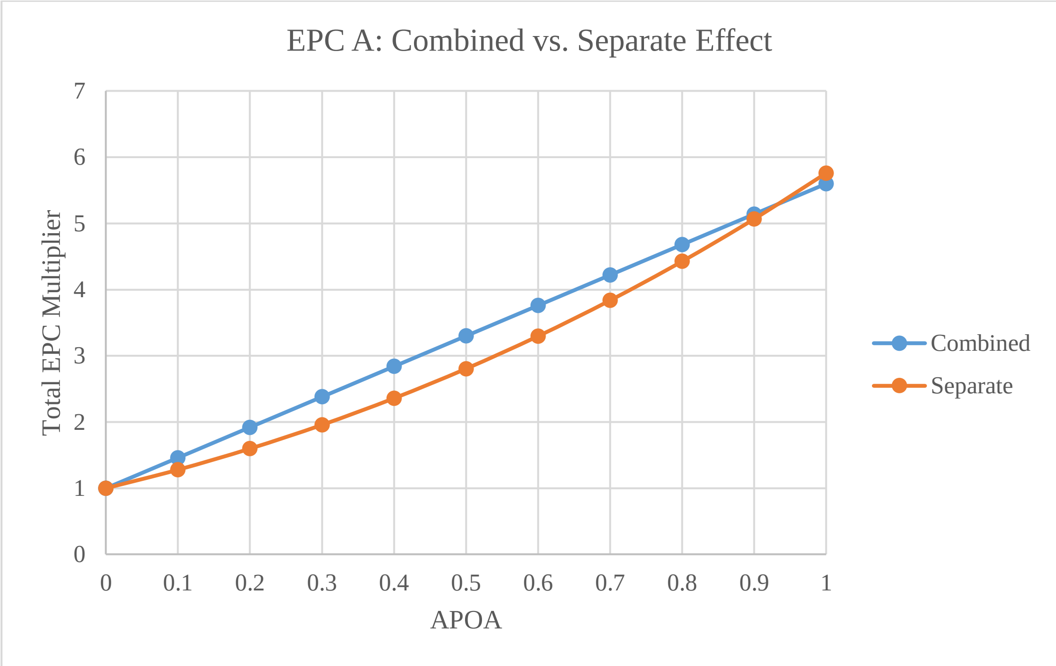


Figure 3-3: Total EPCA Multiplier: Combined versus Separate

As shown in the graph, combining the EPCs increases the multiplier when the APOA is between 0 and 0.934. When the APOA is greater than 0.934, the difference between the separate EPC multiplier versus the combined EPC multiplier is minimal, the largest difference being a factor of 0.16. For EPC B, the difference between separating the EPCs is more significant. Figure 3-4 shows the total multiplier for EPC B separated versus combined.

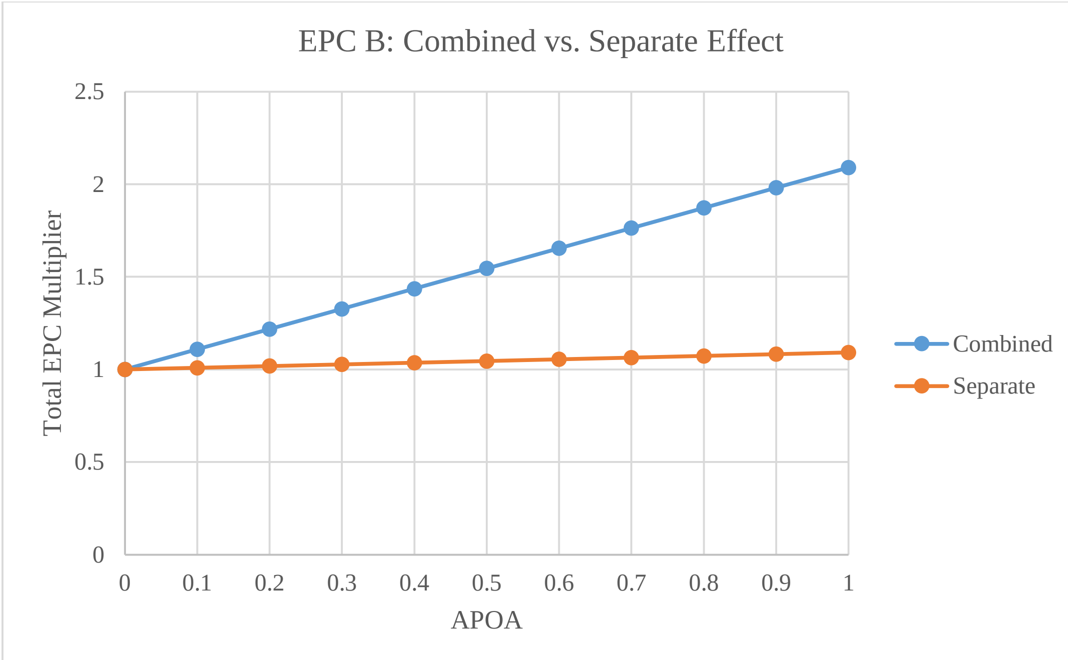


Figure 3-4: Total EPC B Multiplier: Combined versus Separate

Using the EPCs selected by the assessors and the newly created EPCs A and B, a panel of process experts were asked to estimate the APOA of each EPC for all process steps. The next section describes the methods used to gather this information.

## 3.3 Quantifying the Assessed Proportion of Affect

As mentioned in the literature review, one of the key steps in HEART is to find the Assessed Proportion of Affect (APOA) of each EPC relevant to a task. This value serves as a weight, adjusting the power of each EPC's nominal multiplier prescribed in HEART. This is one of the reasons HEART can be applied across various industries and processes, because the weight of each factor depends on the expert estimated APOA. In the original HEART method, the assessor is assumed to have sufficient knowledge of the task and environment to evaluate the APOA of each EPC. However, as in many applications identified in the literature review, it was appropriate to consult process experts for this information, especially as performing a catheter insertion is a specialized skill. Therefore, this research employs a Delphi-type study to estimate the APOA of each EPC through a questionnaire completed by members of an expert panel.

### 3.3.1 Modified Delphi Technique

According to Reid (1998), one way the Delphi technique is “a method for the systematic collection and aggregation of informed judgment from a group of experts on specific questions and issues” (pg. 4, as cited by Keeney, McKenna, & Hasson, 2011). The basic principle of the Delphi method is that the opinions of a group of experts is more valid than the opinion of a single expert (Keeney, McKenna, & Hasson, 2011). This makes the Delphi approach appropriate for this research as the human factors engineer is relying on the judgment of process experts to approximate the APOAs. The final HEP from HEART is also sensitive to expert estimates, therefore it is appropriate to seek input from multiple experts in order to find a valid approximation for each APOA. There is no hard and fast rule for selecting the number of experts for the panel, it is mainly dependent on the context and needs of the study (Keeney, McKenna, & Hasson, 2011). Delphi studies have been conducted with fewer than 10 experts while others have consulted more than 100 experts. Two studies related to healthcare only consulted 5 and 6 experts, respectively (Malone *et al.*, 2005, and Strasser *et al.,* 2005, as cited by Keeney, McKenna, & Hasson, 2011). Healthcare providers often have busy schedules making participation in the study difficult. For this reason, unlike traditional Delphi studies which can be very time-consuming, this research only consults the experts once through a single questionnaire. The expert panel consisted of 8 nurses. In this research, an expert was considered to be a nurse with the following qualifications:

1. Minimum of 5 years of experience
2. Certified registered nurse (RN), minimum

3. Regularly performs catheter insertions or is very familiar with the process (e.g. trains others on the process or is well studied on the process)

The main objective of these criteria was to ensure the panel had sufficient education, experience, and expertise to provide a good estimate of the APOAs. A summary of the characteristics of the expert panel is provided in the table below:

Table 3-3: Summary of Expert Panel Characteristics

| Expert | Position Title | Education | Experience |
|---|---|---|---|
| 1 | Director nursing education program | BSN, RN, CCMA, CMAA | 27+ years long-term care and adult instruction |
| 2 | Infection Control Manager RN | MSN, BSN | 28 years, expertise in Medical/Surgical, ICU, Endoscopy/Urodynamics Lab |
| 3 | Nurse Manager | MSN, RNC - OB | 31 years, 2 months |
| 4 | Nursing Supervisor | BSN, RN | 7.5 years |
| 5 | Nursing Faculty | BSN, RN | 25+ years |
| 6 | Nurse Supervisor, Emergency Department | BSN, RN, CEN | 37 years |
| 7 | RN | BSN | 32 years |
| 8 | Infection Prevention Supervisor | RN | 15+ years |

As shown in the table, the expert panel used in this study had good experience with nursing in general, and especially with urinary catheters and infection control, as well as good levels of educational achievement. Most of the experts consulted also hold a leadership position within their organization or are involved in training other nurses, which indicates a strong understanding of the process. Each expert completed the questionnaire individually online. The questionnaire is described in more detail in the next section.

### 3.3.2 The Questionnaire

The questionnaire distributed to the expert panel utilized Graphic Rating Scales (GRS) to estimate each APOA. Graphic Rating Scales have been used in many different fields of research, and in particular was used by Chadwick and Fallon (2012) while applying HEART to a radiotherapy treatment task. They discussed that the use of GRS is ideal for HEART because it is easy to use and has been shown to be a fairly reliable survey method (Cook et *al.*, 2001). GRS also enables researchers to easily collect continuous data, making it even more appropriate for evaluating APOAs.

The scale used in this research is shown below:


Figure 3-5: APOA Question Scale

This scale is similar to that used by Chadwick and Fallon (2012), where the length of the scale is divided into 5 categories with the linguistic descriptors “Negligible”, “Minor”, “Moderate”, “Major”, and “Extreme”. The use of 5 descriptive anchors is supported by McKelvie (1987) as “subjects using the continuous scale appeared to be operating essentially with five or six categories” (pg.198). As shown above, the scale is labeled from 0-10 with 1 decimal place, allowing the assessor to make finer distinctions at their discretion. A study by Cook *et al.* (2001) found that the reliability of a 1-100 GRS was only slightly higher than that of a 1-9 scale and 1-100 scale. For this research it was appropriate to use a 10-point scale that would be more familiar to healthcare providers where the coarseness is the same as a traditional GRS.

The questionnaire used in this research was constructed so that each page presented a different step in the catheter insertion process with a GRS for each applicable EPC. The final page asked the expert to evaluate the significance of each step to the overall process using the same GRS used to estimate each EPC's APOA. The questionnaire was distributed by email using an anonymous link, and consisted of a total of 245 questions, requiring approximately 1 hour to complete. The questionnaire instructions are included in Appendix E. After collecting responses the results were analyzed and used in the final step of HEART to calculate the probability of a CAUTI. The analysis methods are described in the next section.

## 3.4 Assessed Proportion of Affect Analysis Methods

After gathering expert opinions via the online questionnaire, several steps were taken to synthesize the results and determine the process human unreliability from HEART. Figure 3-6 below gives a summary of these steps:

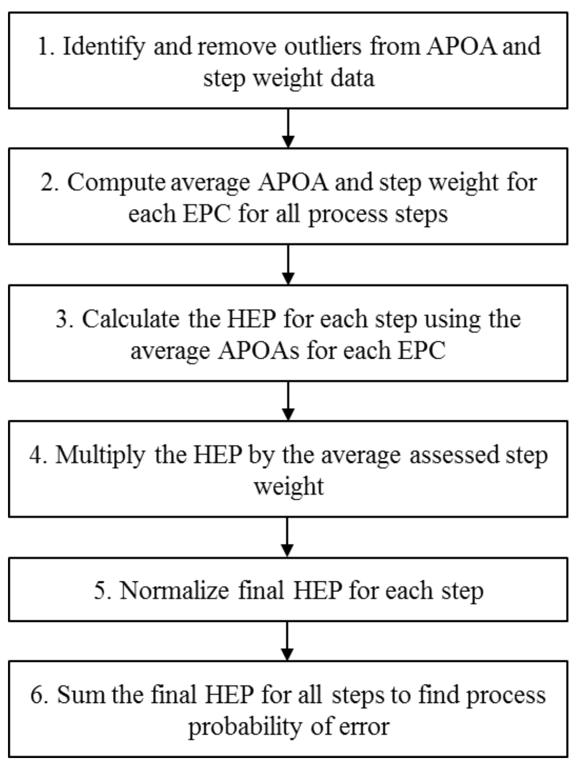


Figure 3-6: Process Probability of Error Calculation Steps

The first step in the APOA analysis was converting the response values provided by the questionnaire to a proportion by taking the original response value and dividing by 10. This yielded APOAs between 0 and 1 as required in HEART. As mentioned in the previous section, this research uses a Delphi-like approach to obtain the expert opinion utilized in HEART. Because this study only uses one round to gather expert opinions, responses were tested for outliers by identifying any responses above or below 1.5 times the interquartile range. These responses were removed before continuing with the analysis.

The next step was to combine the expert opinions to generate one APOA for each EPC and step. According to Keeney, McKenna, and Hasson (2011), "the main statistics used in Delphi studies are measures of central tendency (mean, median, and mode), and the level of dispersion (standard deviation and inter-quartile range) in order to present information concerning the collective judgments of respondents" (pg. 84). Therefore, the mean and standard deviation were found for each APOA (see Table B-3 in Appendix B). These values were used to find the total factor multiplier for each step, as shown in Equation 3, below:

$$Total\ EPC\ Multiplier_k = \prod_{i=1}^{n}(EPC\ \ Multiplier_i - 1) \times (Average\ APOA_i) + 1 \qquad (3)$$

where $n$ is the number of EPCs corresponding to process step $k$, EPC Multipliers can be found in Tables 2-1 and 2-2, and average APOA is in the range of 0 to 1.

The same methods were used to find the assessed weight of each step in the overall process. The weights were used to rank the importance, or criticality, of correctly performing each step. This counters the assumption that an error in each step contributes equally to the probability of CAUTI. For example, it is unlikely that an error in performing the step "remove paper cover" has the same effect on the probability of CAUTI as "wash hands and don clean gloves". This step is not included in the original HEART method, however, the information provided in this step generates an adjustment used to estimate the significance of steps where it is not well defined. Therefore, the total factor multiplier found from each step's EPCs was multiplied by the step weight to find the final HEP modifier, as given by Equation 4, below:

$$Final\ HEP\ Modifier\ for\ Step\ k = Total\ EPC\ Multiplier_k \times Step\ Weight_k \quad (4)$$

where the Total EPC Multiplier is found using Equation 3, and Step Weight is in the range of 0 to 1.

After finding the final HEP modifier for each step, the last step in HEART is to multiply the final HEP modifier by the proposed NHU according to the appropriate task type, resulting in the HEP, or probability of failure, for each step. Assuming that each step is independent, the sum of all individual probabilities was used to find the overall probability of error during catheter insertion, or $P_0$. Equation 5, below, summarizes this calculation:

$$Total\ HEP = NHU \times \sum_{k=1}^{l} Final\ HEP\ Modifier_k \quad (5)$$

where the NHU values are given in Table 2-3 for each task type and the Final HEP Modifier is found using Equation 4.

One key assumption in the proposed model is that all steps are of the same generic task type. Because the catheter insertion process does not easily fit into one of the generic task types, the probabilities resulting from different task types were compared. By nature of a probability, the value of $P_0$ must be between 0 and 1. After calculating the sum of all individual probabilities of failure, the resulting value was greater than 1. Therefore, in order to obtain a valid probability, the original probability of failure for each step was normalized before combining them to calculate $P_0$. There were two important criteria considered when deciding which normalization technique would be most appropriate. First, as mentioned, the resulting probabilities must be in the range of 0 to 1. Second, the normalization method used should preserve the ranking of steps in terms of unreliability as assessed by the expert panel. One of the most common normalization methods is the min-max in method, which normalizes data on a 0 to 1 scale (D. Larose and C. Larose, 2015). For this application, however, using this method would result in the most unreliable step with a probability of failure of 1, and the most reliable step with a probability of 0. This implies that the resulting $P_0$ would still be greater than 1. Another method that ensures that all probabilities would be in the range 0 to 1 is decimal scaling, which transforms data according to Equation 6, below (D. Larose and C. Larose, 2015):

$$X^*_{decimal} = \frac{X}{10^d} \tag{6}$$

where *d* is the number of digits in the data value with the largest absolute value.

This method guarantees that the largest probability value given by the original calculations will be less than 1, along with all other probabilities. Therefore, this normalization technique was applied to the original individual probabilities of error and different models were created based on different task types combined with key patient factors. These models are discussed in detail in the next chapter.

## 3.5 Combining HEART and Patient Factors

As mentioned in the previous section, the normalized individual probabilities of error were added together to find $P_0$. This probability represents the likelihood of an error in the catheter insertion process leading a CAUTI, and therefore can be interpreted as the best case probability of the patient getting a CAUTI on day 0. The best case is defined as a patient with the following attributes:

- Gender: Male
- Diabetes: No
- Obese: No

Literature shows that gender and diabetes are two of the most significant patient factors that can increase or decrease the probability of CAUTI. Female gender and the presence of diabetes both increase the likelihood of CAUTI, therefore male gender and no diabetes are used to describe the base reference case.

Using this definition:

$$P_0 = P(CAUTI|Male, No\ diabetes, Not\ Obese) \\ = HEART\ Probability\ of\ Error, exluding\ OBS$$

$$P_{0,obese} = P(CAUTI|Male, No\ diabetes, Obese) \\ = HEART\ Probability\ of\ Error, including\ OBS$$

In order to account for the added risk for female gender and diabetes, the relative risks given by Maki and Tambyah (2001) were applied as multiplying factors of $P_0$. The relative risk for diabetes was given as a value in the range 2.2 to 2.3, therefore a relative risk of 2.25 was used in the models. The relative risk for female gender was given as a value in the range 2.5 to 3.7. Because of the range is large, two separate female cases were considered, the best case female patient (RR = 2.5) and worse case female patient (RR =3.7).

Obesity was also considered when determining which EPCs may be relevant to the catheter insertion process. Obesity was considered from a task unreliability perspective, adding additional unreliability to each step of the process due to the EPCs introduced while inserting a catheter for an obese patient. There are 26 unique steps in catheter insertion process, therefore, the total unreliability added to the process for an obese patient was 26 times the calculated human unreliability from HEART for the step "OBS".

Based on these factors, there were a total of 12 cases considered as shown in Table 3-4. A key assumption of the proposed model is that the patient factors are independent. This is consistent with current literature, however, if the factors are not independent the model should be adjusted according to the appropriate relative risks.

The other critical factor affecting the probability of CAUTI consistently cited in literature is the number of catheter days. According to literature, the risk of CAUTI increases by approximately 3% to 7% per day (NHSN, 2017), therefore the models consider an increase in the probability of CAUTI of 5% per catheter day.

Combining $P_0$ and $P_{0,obese}$ that result from HEART, the critical patient factors, and catheter days, the probability of CAUTI on day t is given for each patient case in Table 3-4, below:

Table 3-4: Patient Cases and CAUTI Probability Equations

| **Case** | **Gender** | **Diabetes** | **Obese** | $\boldsymbol{P(CAUTI \mid T = t)}$ |
|---|---|---|---|---|
| 1 | Male | No | No | $P_0(1.05)^t$ $(reference)$ |
| 2 | Male | No | Yes | $P_{0,obese}(1.05)^t$ |
| 3 | Male | Yes | No | $(2.25)P_0(1.05)^t$ |
| 4 | Male | Yes | Yes | $(2.25)P_{0,obese}(1.05)^t$ |
| 5 | Best Case Female | No | No | $(2.5)P_0(1.05)^t$ |
| 6 | Best Case Female | No | Yes | $(2.5)P_{0,obese}(1.05)^t$ |
| 7 | Best Case Female | Yes | No | $(2.5)(2.25)P_0(1.05)^t$ |
| 8 | Best Case Female | Yes | Yes | $(2.5)(2.25)P_{0,obese}(1.05)^t$ |
| 9 | Worst Case Female | No | No | $(3.7)P_0(1.05)^t$ |
| 10 | Worst Case Female | No | Yes | $(3.7)P_{0,obese}(1.05)^t$ |
| 11 | Worst Case Female | Yes | No | $(3.7)(2.25)P_0(1.05)^t$ |
| 12 | Worst Case Female | Yes | Yes | $(3.7)(2.25)P_{0,obese}(1.05)^t$ |

Using different values for human unreliability according to different task types, five different models were developed. These models, including the final model selected, are discussed in the next chapter.

# Chapter 4 - Results

The methods discussed in the previous chapter were used to analyze the results of the questionnaire and develop a CAUTI probability model. A discussion of the questionnaire responses is provided in section 4.1. The CAUTI models developed using the response data and HEART are discussed in section 4.2, and an analysis of the final proposed CAUTI model, including a discussion of practical ways the model can be applied in process improvement efforts, is provided in section 4.3.

## 4.1 Analysis of Questionnaire Responses

As mentioned in the previous chapter, a questionnaire was completed by all of the members of the expert panel to evaluate: 1) APOA for each EPC for each process step, and 2) the importance of each step as it relates to the process as a whole (i.e. step weight) using a 10-point scale divided equally into 5 regions: “Negligible”, “Minor”, “Moderate”, “Major”, and “Extreme”. Among the 243 questions with numerical responses, a total of 21 outliers (17 in the APOA data and 4 in the step weight data) were identified. A complete table of responses can be found in Tables B-1 and B-2 in Appendix B. These data points were removed from the dataset before further calculations were performed. As previously mentioned, the original data was transformed from a 0-10 scale to a 0-1 scale. Figure 4-1 shows the average of each APOA versus its standard deviation.

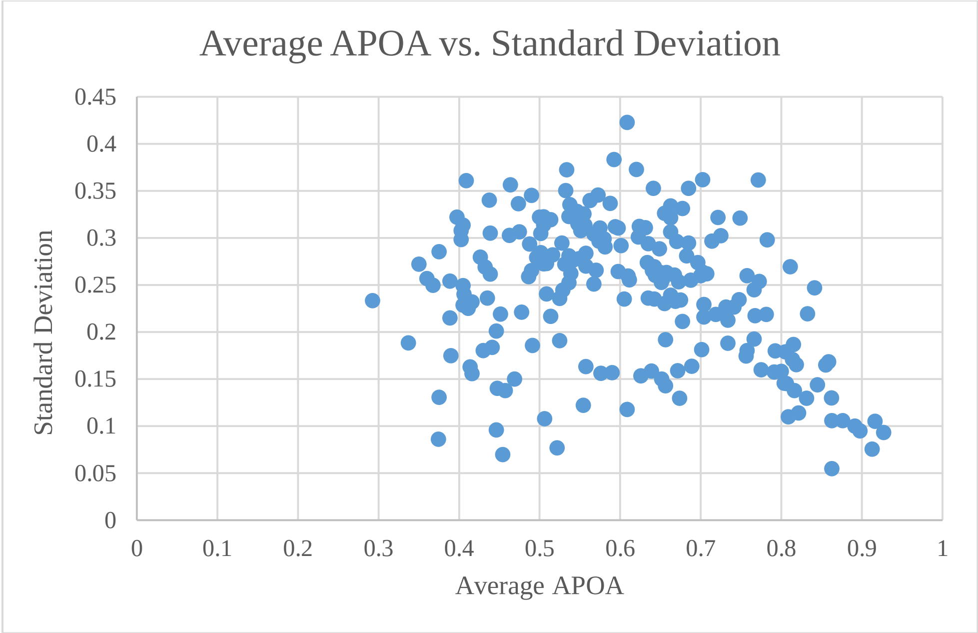


Figure 4-1: Average APOA vs. Standard Deviation

The graph shows that as the EPC was considered to have more of an effect on the step (i.e. the average of the APOA increased), the lower the standard deviation. This shows that there tended to be strong consensus among experts for EPCs with a significant effect on the reliability of a step. For EPCs where the average APOA was more moderate, the standard deviation tended to be higher. This shows that the variability tended to be greater between expert opinions for EPCs in the range “Minor” to “Major”.

For the scale used after transforming the data, a standard deviation of 0.25 implies that, on average, expert opinions differ by one linguistic category above or below the average assessment. In the same way, a standard deviation of 0.50 or signifies that the disagreement among experts separated their opinions by more than two linguistic categories. After analyzing the APOA estimations with outliers removed, there were no EPCs identified where the expert opinion differed by more than two linguistic categories. There were many EPCs identified, however, where the standard deviation was between 0.25 and 0.50. Table 4-1 below gives the steps and respective EPCs for which this occurred:

Table 4-1: Steps and EPCs with a standard deviation ≥ 0.25

| Step | EPCs |
|---|---|
| 1 | 1, 8, A |
| 2* | 1, 5, A, B |
| 3 | 1,8 |
| 4 | 4 |
| 5 | 1, 8, 9, A |
| 6 | 1, 8, A |
| 7* | 1, 2, 4, 8, A, B |
| 8 | B |
| 9* | 1, 2, 5, 6, 9, A, B |
| 10* | 1, 7, A |
| 11 | 7, A |
| 12* | 1, 7, 28, A, B |
| 13* | 1, 9, 15, A, B |
| 14* | 1, 6, A |
| 15 | 9, 23, A |
| 16 | A |
| 17A* | 1, 2, 12, 21 |
| 17B | A, B |
| 17F | 1, 17, A |
| 17M* | 1, 2, 12, 21, A, B |
| 18* | 1, 2, 4, 7, 11, 14, A |
| 19* | 1, 2, A, B |
| 20 | 1 |
| 21* | 1, 4, 9, 15, A, B |
| 21.1 | 1, 15 |
| 22* | 1, 6, 9, 12, 15 |
| 23* | 4, 6, 9, 12, 18, A, B |
| 24* | 1, 15, 16, 18, A |
| 25 | 1 |
| 27* | 1, 9, 15, A |
| OBS | 20, 24, A |

*Step has more than half of EPCs evaluated listed in table

There were no steps where all EPCs evaluated had a standard deviation greater than 0.25, however, there were a total of 16 steps where at least half of the EPCs evaluated did have a standard deviation greater than 0.25. In future work these steps and EPCs could be reexamined.

The same analysis was applied to the step weights found in the second part of the questionnaire. Figure 4-2, below, shows the average of each step weight versus its standard deviation:

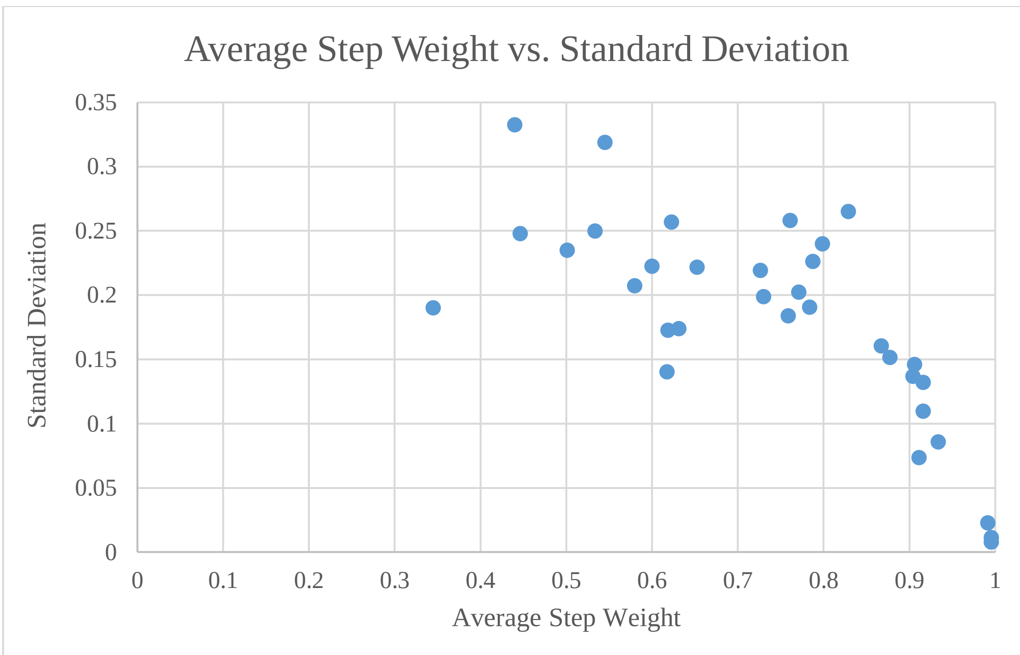


Figure 4-2: Average Step Weight vs. Standard Deviation

Similar to the results for the average APOA, the graph shows that as the significance of the step increases, the standard deviation tends to decrease, and as the significance of the step becomes more moderate, the standard deviation increases. There were no steps identified where the standard deviation was greater than 0.5, however, there were 5 steps identified where the standard deviation was greater than 0.25, in future work these steps could be reexamined:

- Step 2: Remove paper cover

- Step 6: Remove gloves and perform hand hygiene with provided alcohol hand sanitizer gel
- Step 8: Read “Directions for Use”
- Step 13: Position fenestrated drape on patient
- Step 21: Secure the Foley catheter to the patient (Use the STATLOCK Foley Stabilization Device if provided)

## 4.2 CAUTI Probability Models

As mentioned in the previous section, CAUTI probability models were created using the data analyzed above, and five models were generated based on different generic task types. The first model considered was for generic task type G, which has a corresponding proposed NHU of 0.0004. The resulting $P_{0,healthy}$ for the reference case (male, no diabetes, not obese) is 0.2544. The graph in Figure 4-3 shows the development of the probability of CAUTI with respect to catheter days for different patient cases. As mentioned in the literature review, according to the National Healthcare Safety Network (NHSN), a CAUTI cannot be diagnosed until catheter day 2, therefore each graph shown in this section will start on day 2.

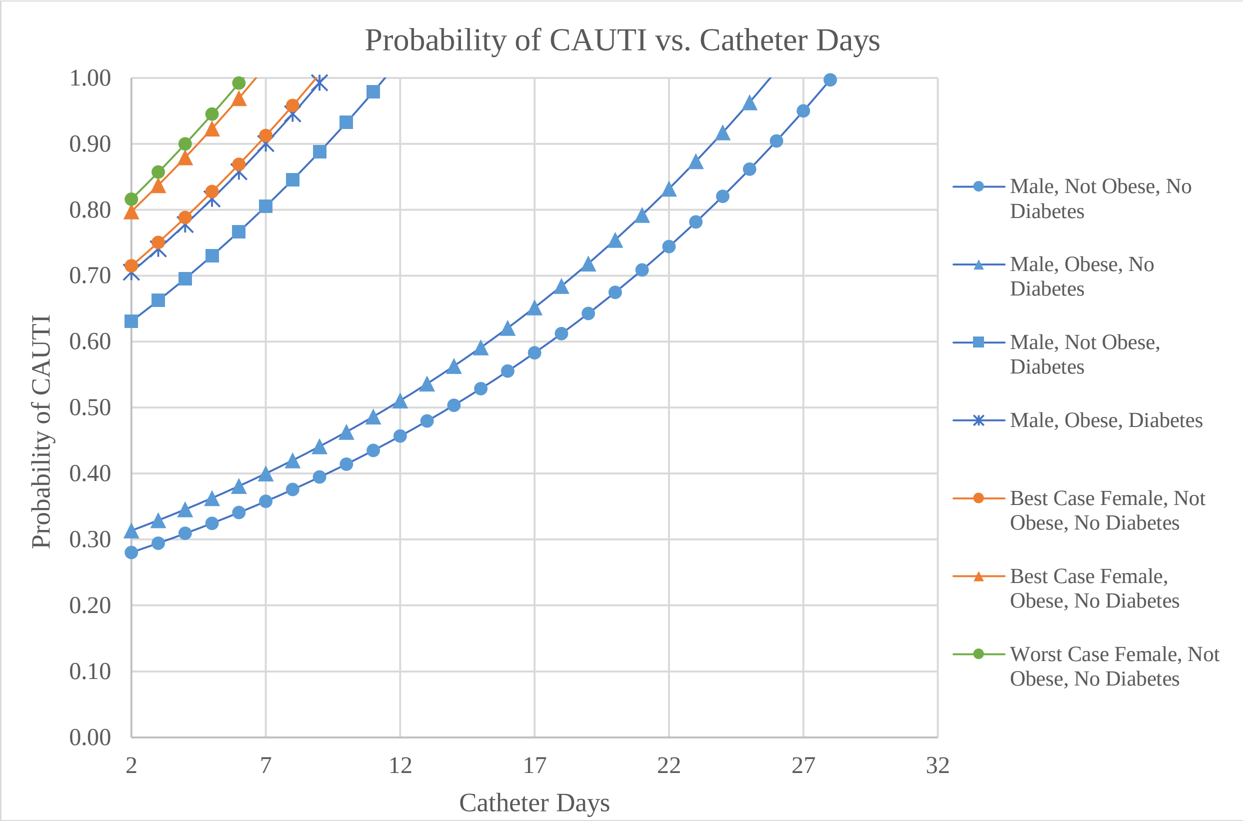


Figure 4-3: CAUTI Model for Task Type G

As shown in the figure, the probability of CAUTI for the reference case male exceeds 1 on day 29. This is consistent with literature that reports that CAUTI is practically universal by day 30. There are other logical aspects of the model, such as the fact that the probabilities become more pessimistic for obese patients versus patients who are not obese, and patients with diabetes versus those without. The limitation of this model, however, is that for the best-case female with diabetes, both obese and not obese, the corresponding $P_0$ is greater than 1. All worst-case female patient cases, except the case for a female who is not obese or diabetic, also have $P_0$ greater than 1. Therefore, this model was considered to be too pessimistic and other models were considered.

Another model was created using the 5$^{th}$ percentile value for task type G. Due to the nature of the normalization technique used, the resulting model was more pessimistic than the model for nominal task type G. This was also true for the model resulting from the 95$^{th}$

percentile value for task type G. Task type F, however, generated a more optimistic model after normalization. The $P_0$ for the reference case for task type F is 0.1908; Figure 4-4 below shows the graph of the probability of CAUTI over time for the different patient cases:

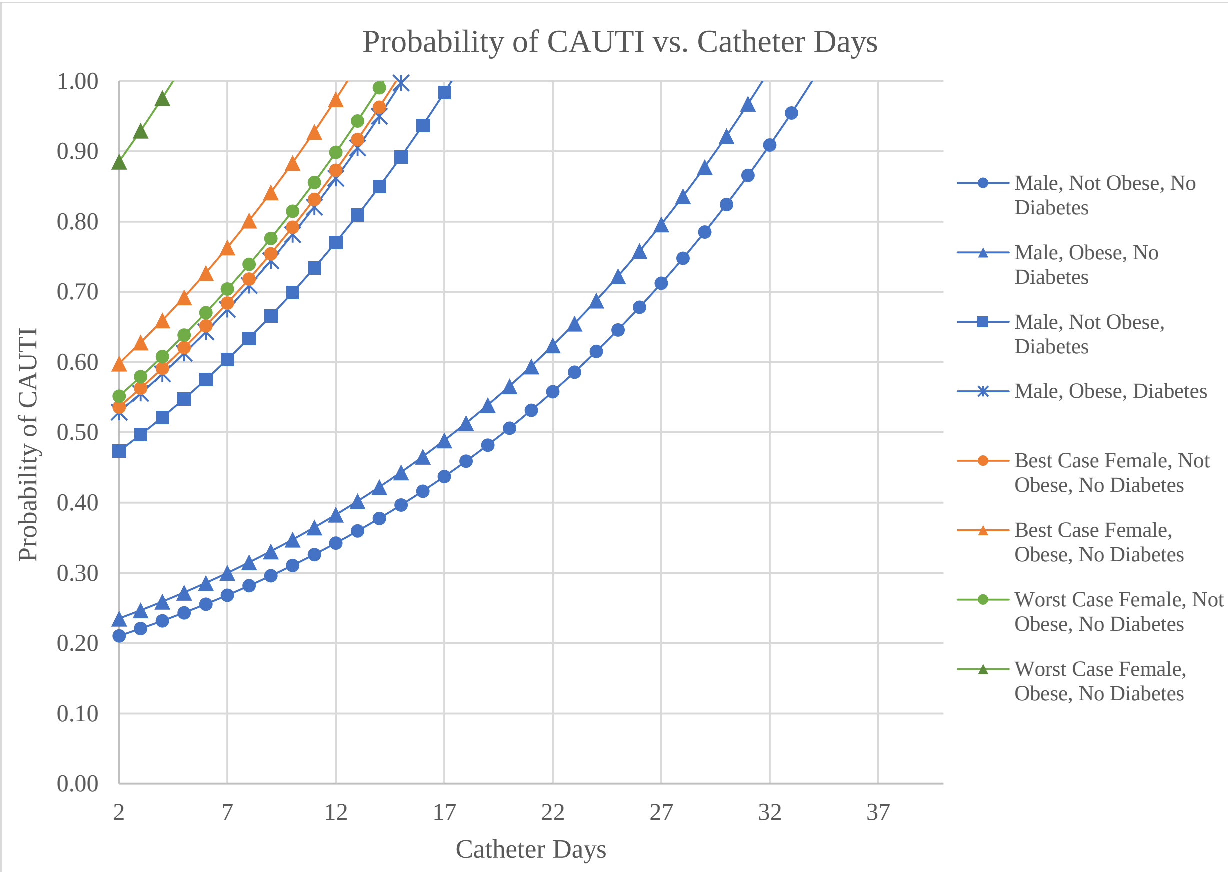


Figure 4-4: CAUTI Model for Task Type F

This model is more optimistic as it shows the reference case probability exceeding 1 on day 34, and includes the worst-case female patient cases without diabetes. The model is not feasible for the best case female with diabetes, however, so it was also considered to be too pessimistic. Two other task types were considered, task types E and H. A model was generated using the nominal value for both task types, as well as for the 5$^{th}$ percentile human unreliability value for task type E. The model for the 5$^{th}$ percentile task type E human unreliability was also too pessimistic after normalization with a reference case $P_0$ of 0.4452. After normalization, task type E and task type

H generated the same probabilities. This is logical due to the fact that the nominal human unreliability of task type E is exactly 4 orders of magnitude greater than the nominal value for task type H. The resulting reference case $P_0$ is 0.1272. Figure 4-5 below shows the graph of probability of CAUTI models over time for task type E/H:

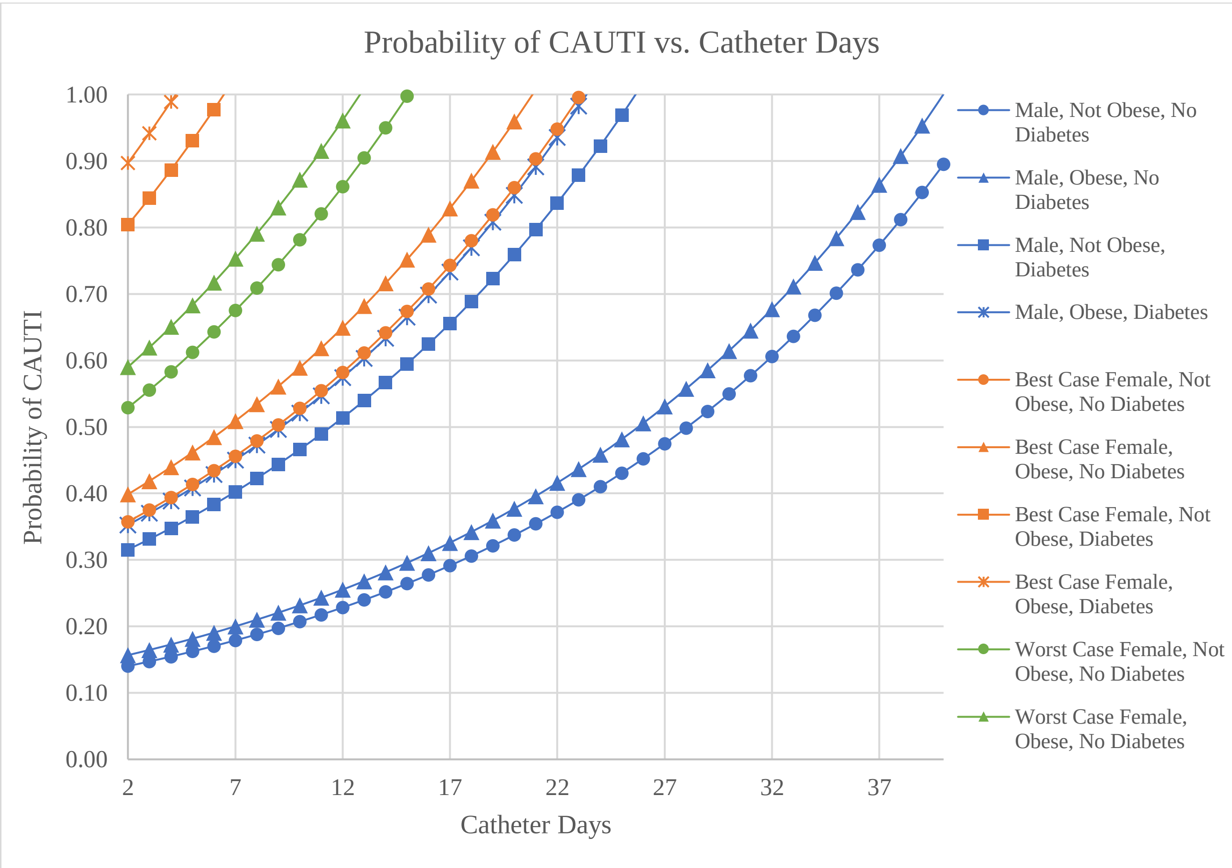


Figure 4-5: CAUTI Model for Task Type E/H

The model for task type E/H shows the probability of CAUTI exceeding 1 around day 42 for the reference patient case. This is a similar result for the reference patient case for task types F and G. Unlike the other models, however, the model for task type E/H is feasible for all patient cases except for the worst-case female patients with diabetes. This is an acceptable result as the relative risk for female gender is cited between the range of 2.5 to 3.7 (Maki and Tambyah, 2001), and the worst-case relative risk may be too pessimistic. Table 4-2 below gives the number of catheter days before the patient's risk of infection reaches or exceeds 1 based on the models for task type E/H:

Table 4-2: Catheter Days until Probability of CAUTI Exceeds 1 for each Patient Case

| **Case** | **Gender** | **Diabetes** | **Obese** | **Catheter Days until $P(CAUTI)$ exceeds 1** |
|---|---|---|---|---|
| 1 | Male | No | No | 42 |
| 2 | Male | No | Yes | 39 |
| 3 | Male | Yes | No | 25 |
| 4 | Male | Yes | Yes | 23 |
| 5 | Best Case Female | No | No | 23 |
| 6 | Best Case Female | No | Yes | 20 |
| 7 | Best Case Female | Yes | No | 6 |
| 8 | Best Case Female | Yes | Yes | 4 |
| 9 | Worst Case Female | No | No | 27 |
| 10 | Worst Case Female | No | Yes | 15 |
| 11 | Worst Case Female | Yes | No | N/A |
| 12 | Worst Case Female | Yes | Yes | N/A |

The model is logical based on the number of days until a patient's probability of CAUTI reaches 1, roughly 1 month on average for the best-case patient scenarios. Additionally, according to literature, CAUTI rates peak around day 6 (Crouzet *et al.*, 2007), and the model predicts that the probability of CAUTI on day 6 will be greater than 0.50 for 3 out of the 10 cases with feasible probabilities, and greater than 0.4 for 7 out of 10 cases. This model is also consistent with literature on the basis that female patients and patients with diabetes have an increased risk of CAUTI. Therefore this model was considered to be acceptable and was used throughout the rest of this research. A complete table with the probability of CAUTI per day by patient case is provided in Table C-1 in Appendix C.

## 4.3 CAUTI Model Analysis

One of the main benefits of HEART compared to other HRA techniques is that it allows the human factors engineer to analyze the probability of failure in terms of various components of the process. HEART captures information about individual tasks, as well as the specific human factors that affect the tasks. This information is useful for determining which parts of the process should be improved and the impact of such improvements.

### 4.3.1 Identifying Critical Process Steps and EPCs

As mentioned in Chapter 3, the HEART method was used to calculate the individual unreliability for each step. Knowing these values allows the assessor to compare the unreliability of each step to the total process unreliability, revealing steps that contribute more to the probability of error than others. The corresponding percentage of the total unreliability for each step was calculated, and Figure 4-6, below, shows a pie chart of these percentages by process step:

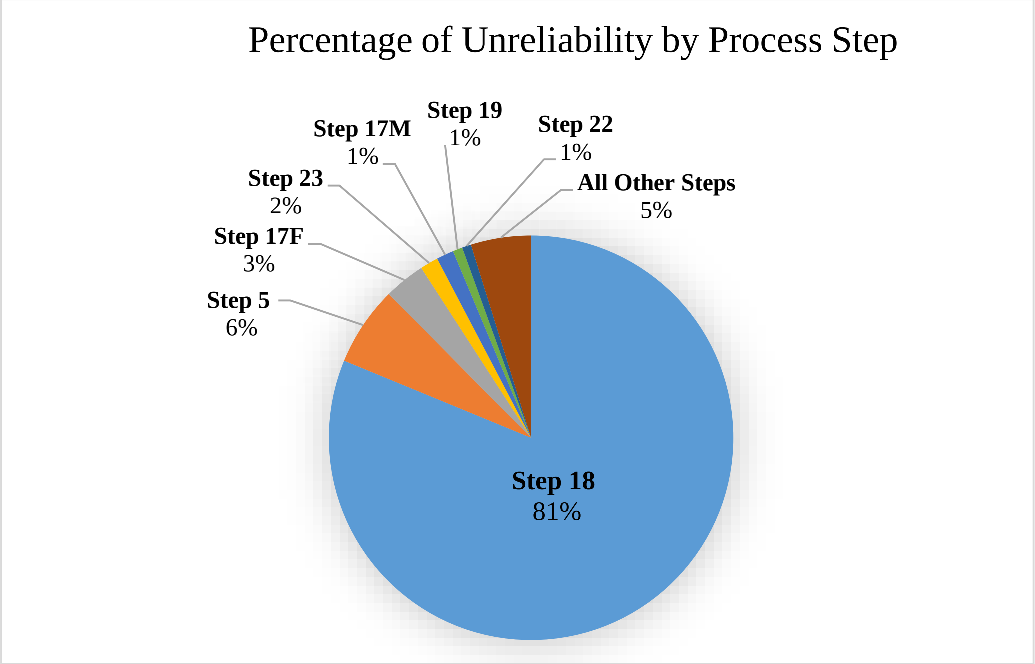


Figure 4-6: Percentage of Total Unreliability by Process Step

Clearly, Step 18, "Proceed with catheterization in usual manner using the dominant hand", contributes the most to the overall process unreliability. The pie chart shows that the other critical steps are Step 5, "Use the provided packet of towelettes to cleanses patient's peri-urethral area”, Steps 17F and 17M, both requiring the healthcare provider to “Prepare patient with 3 foam swab sticks saturated in Povidone Iodine” for female and male patients, respectively, and Step 23, “Use green sheeting clip to secure drainage tube to the sheet”. Additionally, the pie chart shows that only 7 steps make up approximately 95% of the total unreliability of the process. These steps and their full descriptions are listed in Table 4-3, below:

Table 4-3: Top 7 Most Unreliable Steps

| Step | Step Description |
|---|---|
| 18 | Proceed with catheterization in usual manner using the dominant hand:<br>1. When catheter tip has entered bladder, urine will be visible in the drainage tube<br>2. Insert catheter two more inches<br>3. Inflate catheter balloon |
| 5 | Use the provided packet of towelettes to cleanse patient’s peri-urethral area |
| 17 F | Female Patient - Prepare patient with 3 foam swab sticks saturated in Povidone Iodine, then:<br>1. With a downward stroke cleanse the right labia minora<br>2. Discard the swab.<br>3. Do the same (repeat step 1) for the left labia minora.<br>4. Discard the swab.<br>5. With the last swabstick, cleanse the middle area between the labia minora |
| 23 | Use green sheeting clip to secure drainage tube to the sheet |
| 17 M | Male Patient - Prepare patient with 3 foam swab sticks saturated in Povidone Iodine, then:<br>1. Cleanse the penis in a circular motion starting at the urethral meatus and working outward |
| 19 | Inflate catheter balloon using entire 10cc of sterile water provided in prefilled syringe |
| 22 | Position hanger on bed rail at the foot of the bed |

This analysis reveals that of the 27 steps identified in the catheter insertion process, only 7 steps are responsible for almost all of the unreliability. A key assumption of this model is that the individual steps are independent, which may not best represent what physically occurs. Based on literature, however, it is still reasonable to conclude that these 7 steps are critical to the process. Common CAUTI prevention guidelines list maintaining sterile technique (Tambyah and Oon, 2012), which includes cleaning and preparing the patient before and during catheter insertion (Steps 5, 17F, 17M, 18, and 19), as well as ensuring the urine collection bag remains below the patient's bladder (Steps 22 and 23). The analysis shows that these particular steps can be targeted for improvements in order to have the greatest impact on reducing the unreliability of the process. Examples of improvement strategies are discussed in more detail in the next section.

One of the analyses recommended by Williams (1985), HEART's creator, is to analyze each EPC's percent contribution to the final HEP modifier compared to the other EPCs for the corresponding task. This is done by applying Equation 7, below, for each EPC:

$$Percentage\ Contribution\ to\ Unreliability, \%CU = \frac{Assessed\ Effect_i}{\sum_{j=1}^{k} Assessed\ Effect_j} \tag{7}$$

where $k$ is the number of corresponding EPCs for the step analyzed and the Assessed Effect is found using Equation 1.

This equation was applied to each step of the process, and the average percentage contribution to unreliability is given for each EPC in Table 4-4.

Table 4-4: Average Percentage Contribution to Unreliability by EPC

| **EPC** | **Average CU%** | **EPC (Continued)** | **Average CU% (Continued)** |
|---|---|---|---|
| 1 | 42.80% | 13 | 8.92% |
| 2 | 22.06% | 14 | 7.77% |
| 7 | 20.17% | B | 7.32% |
| 6 | 17.05% | 18 | 6.80% |
| 4 | 16.56% | 23 | 6.42% |
| A | 14.12% | 17 | 5.96% |
| 9 | 12.84% | 28 | 5.79% |
| 11 | 12.23% | 20 | 5.51% |
| 12 | 9.94% | 21 | 5.38% |
| 16 | 9.91% | 24 | 4.45% |
| 15 | 9.47% | 27 | 4.29% |

Not surprisingly, the table indicates that the top 2 EPCs in terms of average percentage contribution are EPCs 1 and 2, which have nominal multipliers of 17 and 11, respectively.

Because these EPCs have relatively large nominal multipliers, an equally large corresponding APOA will make it difficult for a more minor EPC to contribute the same amount to the total unreliability. The EPCs more or less follow the order given in HEART based on their nominal multipliers, with a few exceptions. There are a couple of reasons why this analysis may not truly reveal the most important EPCs. First, this analysis method adds the assessed effect of EPCs where in the task unreliability calculation they are multiplied together. As a result, the percent contribution calculation does not directly reflect the comparative effect of each EPC. Second, there are some EPCs that are evaluated 34 times versus once, and the average percent contribution could easily be skewed by an EPC which contributes greatly to a single step rather than an EPC which is less impactful in multiple steps. This would potentially skew the results to make certain EPCs appear more significant than they are.

In order to gain another perspective on the significance of each EPC, the following equation was developed to find the change in $P_0$ for every 1% change in the APOA of a particular EPC* for task *k*, holding all other assessed effects equal:

$$\mathrm{M}_{\%} = (NHU)(Step\ Weight_k)[(EPC\ Multiplier^{*} - 1) \times 0.01 \times APOA^{*}] \times \prod_{i=1}^{j}[(EPC\ Multiplier_i - 1) \times APOA_i + 1] \quad (8)$$

where the NHU values are given in Table 2-3 for each task type, EPC Multipliers can be found in Tables 2-1 and 2-2, and Step Weight and APOA are in the range of 0 to 1.

As discussed in section 3.4, the model assumes that steps and EPCs are independent, and that the unreliability of each step is additive. The same assumption is made when applying Equation 8. The equation was applied to all EPCs across all steps, and a complete list of $\mathrm{M}_{\%}$ values is given in Table D-1 in Appendix D. The total decrease in $P_0$ for a 1% decrease in each APOA of a particular EPC can be found by taking the sum of the EPC's $\mathrm{M}_{\%}$ values across all steps. Table 4-5, below, lists the EPCs from most significant to least significant based on these sums:

Table 4-5: Ranking of EPCs based on Sum of M% (highest to lowest)

| **EPC** | **Sum of $M_{\%}$** |
|---|---|
| 1 | 1.352E-03 |
| A | 1.080E-03 |
| 2 | 1.060E-03 |
| 15 | 9.282E-04 |
| 4 | 8.902E-04 |
| 7 | 8.898E-04 |
| 11 | 7.959E-04 |
| 14 | 7.197E-04 |
| B | 6.839E-04 |
| 12 | 2.406E-04 |
| 9 | 9.023E-05 |
| 20 | 5.978E-05 |
| 18 | 5.730E-05 |
| 24 | 3.842E-05 |
| 27 | 3.404E-05 |
| 6 | 3.392E-05 |
| 17 | 2.370E-05 |
| 21 | 1.584E-05 |
| 16 | 3.986E-06 |
| 13 | 1.201E-06 |
| 23 | 2.713E-07 |
| 28 | 5.313E-08 |

This ranking provides a better understanding of which EPCs are most impactful by comparing how reducing each EPC reduces the total process unreliability. This method accounts for the number of times each EPC is evaluated, as well as the APOA of each step for which it was evaluated. This second analysis shows that EPC 1 is still the most significant EPC across process steps, however, the second most significant EPC is EPC A, personal health factors. The nominal multiplier for this EPC is 5.6, and is the sum of three minor EPCs related to the physical and psychological health of the healthcare provider. These EPCs were combined into a stronger EPC because the team of assessors believed they were significant in every step. This analysis confirms that this is an important EPC because though its nominal multiplier is the 10th highest, it is the 2nd highest EPC in terms of unreliability reduction potential. Similarly, EPC 15, "operator inexperience", with a nominal multiplier of 3, is also in the top 5 most significant EPCs. This is another way to confirm literature discussing importance of nursing expertise and experience in patient outcomes (Orsolini-Hain & Malone, 2007). The other EPCs that appear in the top 5 most significant EPCs, EPC 2, "time shortage" and EPC 4, "features over-ride allowed", are not surprising given that they both have large nominal multipliers. What is interesting is that these EPCs are only evaluated for 7 and 8 steps, respectively, which implies that they were consistently assessed as highly significant.

Based on this information, the next section will discuss in more detail how the process steps and EPCs can be analyzed to prioritize reliability improvement efforts.

### 4.3.2 Using the Model to Prioritize Improvement Efforts

One of the main benefits of having a prediction model is understanding how changes to factors within the model effect the outcome. The CAUTI model developed in this research provides a tool that can be used to inform healthcare providers with information about how a particular reliability improvement effort can reduce a patient's probability of CAUTI. This section discusses how the process steps can be analyzed to prioritize reliability improvement efforts, and how the EPCs can be analyzed to prioritize reliability improvement efforts.

As discussed in the previous section, there are 7 steps that significantly increase the unreliability of the process as compared to other steps. A simple calculation can be performed to determine the effect of reducing the unreliability of a single step on the total process unreliability. For example, Step 5 contributes 6.36% of the total unreliability based on its HEP as compared to the total process unreliability. It follows, therefore, that reducing the unreliability of Step 5 by 50% will reduce the total unreliability by a factor of 50% of 6.36%, or 3.18%. While this calculation is straightforward, a more beneficial analysis is examining the effect of reducing individual EPCs within significant steps.

The $M_{\%}$ values can be used to determine the effects of reducing a single EPC across the entire process or the effects of reducing a specific EPC in a specific step. These values can be added together for a specific EPC for particular steps of interest to find the change in $P_0$ for those steps. For example, the most significant EPC on average is EPC 1, and the total change in $P_0$ for a 1% decrease in EPC 1 in all steps is the sum of all $M_{\%}$ values for EPC 1. The resulting total is 0.00122, which implies that a 10% reduction in EPC 1 would yield a 0.0122 decrease in $P_0$. It may be challenging to implement a process change of this magnitude, however, as it could be difficult and costly to reduce unfamiliarity in every step of the process. Training requires time and resources, and it may make more sense to limit the training to eliminate unfamiliarity in steps related to handling the catheter or cleaning and preparing the patient. EPC 15, operator inexperience, is another EPC where a step-specific approach could potentially be more impactful than examining all steps. The 4 steps with the highest $M_{\%}$ values for EPC 15 are Steps 4, 17F, 17M, and 18 which relate to explaining the procedure to the patient, cleaning the patient prior to inserting the catheter, and inserting the catheter. The total $M_{\%}$ of these 4 steps for EPC 15 is 0.000775, compared to the total $M_{\%}$ for all 27 steps which is 0.000833. Therefore by providing training or assistance for less-experienced healthcare providers in these 4 steps the impact is almost as significant as doing the same for all 27 steps, but is potentially a better use of an organization's resources.

This analysis could be extended to numerous other combinations of steps and EPCs, but based on the results for individual steps discussed earlier, Step 18 should be targeted for reliability improvements above any other step. Because Step 18 contributes more than 80% of the total unreliability, any gains in error reduction for this step have a significant impact on the total unreliability. A list of the EPCs affecting Step 18 and their corresponding probability decrease rates are given in Table 4-6, below:

Table 4-6: Step 18 EPCs and Effects

| **EPC** | **Description** | **$M_{\%}$** | **Decrease in Probability for 25% decrease in EPC** |
|---|---|---|---|
| 1 | Unfamiliarity | 0.000988 | 0.0247 |
| 2 | Time Shortage | 0.000909 | 0.0227 |
| 4 | Features over-ride allowed | 0.000855 | 0.0214 |
| 7 | Irreversibility | 0.000884 | 0.0221 |
| 11 | Performance Ambiguity | 0.000794 | 0.0199 |
| 14 | Delayed/incomplete feedback | 0.000718 | 0.0180 |
| 15 | Inexperience | 0.000684 | 0.0171 |
| A | Personal Health/Time Factors | 0.000787 | 0.0197 |
| B | Outside Influence Factors | 0.000490 | 0.0123 |

As shown in the table, of all of the EPCs for step 18, EPC 1 has the greatest $M_{\%}$ value. Williams (1985) suggests a remedial measure for each EPC, and for EPC 1 the recommended remedial measure is to “train operators to be aware of infrequently-occurring conditions, simulate such situations, and teach an understanding of the consequences” (pg. 5). For Step 18, this could mean training healthcare providers about situations and solutions to particularly difficult catheter insertions, and ensuring healthcare providers understand the risks of attempting to reinsert a catheter multiple times (Ortega *et al.*, 2008). Similarly, EPC 15 could potentially be reduced through training and job aids that assist the inexperienced healthcare provider in situations of uncertainty.

The second most impactful EPC in step 18 is EPC 2, which is time shortage. The recommended remedial measure for this EPC is fairly vague, suggesting only that management be aware of when poor decisions could be made due to a shortage of time. As mentioned, there are a few different reasons why a patient may be catheterized. If a catheter is being used because the patient is in critical condition and requires immediate surgery, then the healthcare providers may need to be reminded that taking a few minutes more while inserting the catheter could prevent future complications associated with CAUTI.

EPCs 4, 11, and 14 are similar in that they are attributed to errors made due to “poor or ambiguous system feedback” (Williams, 1985 pg. 3). These EPCs could possibly be reduced through training that helps healthcare providers understand signs that the insertion was completed correctly. This is also an aspect where technology could play a significant role in improving the reliability of the process. Willette and Coffield (2012) discuss the benefits of utilizing “direct visualization technology” that can assist the healthcare provider during catheter insertion and reduce complications that come with “blind insertion”. This is one form of system feedback introduced by the assistance of technology. According to the proposed CAUTI model, other technology that increases system feedback for the healthcare provider would be worthwhile as decreasing these three EPCs 25% each would decrease the probability of CAUTI by 0.0593, translating to an additional 12 days before the best-case diabetic female patient reaches a probability of CAUTI of 1. The issue of “irreversibility”, EPC 7, is difficult to mitigate in this process as once bacteria has entered the urinary tract it is difficult to reverse the process and remove the bacteria. This is another area where new innovative technology could assist the healthcare provider by creating a “poka yoke” or “mistake-proof” process. Technology such as cameras and sensors could be used to detect an error before it occurs by understanding what the correct state of the system should be and the steps taken to get to each state. For example, a camera or sensor could detect when a catheter is being inserted with the non-dominant or non-sterile hand and create a signal or alert that the healthcare provider is violating sterile technique.

The other EPCs related to personal health factors and outside influences (i.e. other personnel or patient guests) are also potentially difficult to control or reduce, however, having an awareness that these EPCs affect the process could be used to inform policies that help prevent errors. For example, it may be necessary to develop a policy regarding the maximum number of hours a healthcare provider can be on duty and still perform an insertion or the number of people or personnel that can be present when performing an insertion. These are all possible remedial measures, but ultimately the healthcare providers should be actively involved in determining the appropriate solutions to be implemented to reduce relevant EPCs.

As mentioned, this analysis could be completed for any step or individual EPC, or combination thereof. While HEART provides a general remedial measure for each EPC, the real advantage of HEART is that it provides a systematic way to prioritize which EPCs and steps to target in improvement efforts. Steps that introduce the most unreliability should be prioritized over other more reliable steps, and EPCs with a greater effect on the unreliability should be reduced before less significant EPCs are addressed.

# Chapter 5 - Conclusions

HEART was applied to the catheter insertion process and a CAUTI predictive model was developed combining human error probabilities with critical patient factors. This is the first model that uses HEART to predict CAUTI, and it is also the first model based on HRA techniques that examines the impact of patient obesity on the process reliability. The model reveals that there are specific process steps and EPCs that have the greatest comparative effect on CAUTI development. In addition, this research confirmed and exposed many of HEART's strengths and weaknesses as an HRA technique, especially as they relate to the method's application in healthcare. The findings from the proposed model, the strengths and weaknesses of HEART, and areas of future research, are all discussed in this chapter.

## 5.1 Findings from the Proposed CAUTI Model

The proposed CAUTI model was developed using the total HEART HEP as the initial probability and taking into account the patient's gender, diabetic status, obesity, and catheter days. The model showed that for the best case patient, a male with no diabetes and not obese, the initial probability of CAUTI is 0.1272 and will not exceed 1 until catheter day 43. For the worst case patient, a female who is obese and has diabetes, the initial probability of CAUTI is 0.814 and will exceed 1 on catheter day 5. In addition to this information, the model also provided much more information related to crucial steps and EPCs that have the greatest effect on the process's unreliability. The model shows that actual catheter insertion step is by far the most important step, but also that only 7 of the 27 steps contribute 95% of the total HEP. In general, these steps are associated with cleaning the patient before inserting the catheter, inserting the catheter, and setting up a clean collection system after the catheter is inserted. The EPC analysis showed that within the process, the most important EPCs affecting human error are:

unfamiliarity, personal health and time factors, time shortage, operator inexperience, and poor system feedback. Further analysis showed that reducing unfamiliarity or time shortage by 25% in the catheter insertion step alone would decrease the baseline probability of CAUTI by at least 0.022, translating to an additional 3 days before the probability of CAUTI exceeds 1 for the worst case patient. Therefore, the model offers valuable information about how process improvement efforts should be prioritized in order to have the greatest impact on preventing CAUTI.

## 5.2 HEART in Healthcare

As mentioned in the literature review, there are a few benefits of using HEART over other HRA techniques, and this application confirmed some of those benefits. First, collecting APOA data for each step and EPC was simple as it only required a single online questionnaire. Once the data was gathered from the questionnaire, only a few transformations were required to use the data in HEART. Another benefit recognized in this research is that the technique is inherently simple mathematically and does not require complex or special software. All of the analyses presented here were done using Microsoft Excel spreadsheets, and could easily be implemented using common coding languages. Finally, perhaps the greatest benefit of HEART over other HRA techniques is that the method analyzes various environmental factors utilizing 40 different EPCs. This allows the human factors engineer to isolate and evaluate the impact of different factors in greater detail, which in turn can be used to develop a more efficient and strategic approach to improve the process being analyzed. As shown in this research, only 7 of the 26 step examined were significant, which is highly useful information to healthcare organizations that typically have overstretched resources.

Along with providing many benefits, applying HEART in this context also proved to be difficult for several reasons. While the data collection process was simple and easy to implement through an online platform, actually collecting complete responses was difficult. This is somewhat to be expected when working in healthcare as individuals tend to be busy with limited time to participate in research. The lack of respondents can also limit the amount of data that can be collected as longer questionnaires usually imply a lower response rate, therefore causing the human factors engineer to choose between a better response rate or better information gathered. I chose to pursue better information by finding a smaller group of experts with both excellent experience and education that would be willing to complete a longer questionnaire. This exposes another potential weakness of HEART in that it is subjective to expert judgment, though within set parameters. This research also showed that HEART does not adjust well for tasks with 4 or more EPCs. In many cases healthcare processes are highly specialized and complex, which is reflected in the number of EPCs used to evaluate the reliability of the process. Using the technique as it was originally developed, HEART produced a probability of failure that was far too pessimistic in this application. This could be attributed to the number of EPCs evaluated or the number of process steps analyzed. The most appropriate way to find a probability from the data was to normalize it such that the implied the nominal task unreliability was lower than lowest value proposed by Williams (1985).  It should be noted that HEART was originally proposed for use in the nuclear industry, and the difficulties encountered in this application suggest it may not be readily applicable to all healthcare processes.

Despite some of the weaknesses of HEART as a technique to develop the probability of error in a process, HEART has shown to be useful for estimating and understanding the comparative impact of multiple factors that affect a task. The analyses performed in this research show how the data collected to develop the HEART probabilities can be used to prioritize process improvements. These comparisons are valid whether or not the numerical representation of the significance of each EPC is valid. Ultimately, the proposed model may not provide the best representation of how CAUTI develops, however it does provide insight into the healthcare providers' perceptions about how CAUTI develops. This is just as strong of a result because the healthcare providers play a critical role in all catheter-related processes. Because there are many useful aspects of HEART, it may be appropriate to develop a different version of HEART for healthcare applications.

## 5.3 Future Work

As alluded to in previous sections, this research could be extended in many ways. First, the results of this research could potentially be strengthened by reexamining the steps and EPCs that showed the greatest variance in expert opinion. This could be accomplished conducting a Delphi study with multiple rounds, though as discussed, it may be difficult to find a group of experts dedicated to participating in the study to completion.

In a broader context, the analysis could be expanded to use HEART to estimate human unreliability in other catheter processes such as catheter maintenance and catheter removal. These processes should be studied to get a more holistic view of how CAUTIs develop, and therefore increase the knowledge base to prevent CAUTI. CAUTI is just one of several common HAIs, however, and this research could be extended by applying HEART to analyze human factors in the development of HAIs such as surgical site infections (SSIs), central line associated bloodstream infections (CLABSIs), and ventilator-associated pneumonia (VAP). As discussed in the previous section, the most appropriate first step before applying HEART to other HAIs may be to develop a HEART methodology specifically designed for healthcare applications. The modified method should be able to estimate human unreliability for processes with multiple steps where there are likely multiple EPCs affecting each step. It should also examine the nominal multipliers of each step, because as revealed in this research, factors such as psychological health factors or the presence of extra personnel may be underestimated in the original HEART method.

Finally, this research could be validated in a real healthcare setting by comparing the probabilities given by the model to real hospital data, or by implementing some of the process improvement strategies and evaluating whether the results are consistent with the predicted results. The goal of HEART is to understand the underlying mechanisms of human unreliability in a task, and as a result, to be able to reduce human unreliability, in order to create a safer and more predictable environment. With more research in how to best apply HEART in healthcare, it could be a very valuable tool.

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# Appendix A - Catheter Insertion Process Steps

Table A-1: Catheter Insertion Process Steps

| Step | Step Description |
|---|---|
| 1 | Read: STOP – Does this patient meet the CDC guidelines for indwelling urethral catheter use? |
| 1.1 | Mark reason for catheterization |
| 2 | Remove paper cover |
| 3 | Wash hands and don clean gloves |
| 4 | Explain procedure to patient and open Peri-Care Kit |
| 5 | Use the provided packet of towelettes to cleanse patient's peri-urethral area |
| 6 | Remove gloves and perform hand hygiene with provided alcohol hand sanitizer gel |
| 7 | Read "Patient/Family Education: Your Foley Catheter" sheet to patient |
| 8 | Read "Directions for Use" |
| 9 | Fill out Orange sticker sheet before proceeding |
| 10 | Using proper aseptic technique open CSR wrap, oriented toward insertion site |
| 11 | Don sterile gloves |
| 12 | Place underpad beneath patient, plastic/"shiny" side down |
| 13 | Position fenestrated drape on patient |
| 14 | Saturate 3 foam swab sticks in Povidone Iodine |
| 15 | Attach the water filled syringe to the inflation port |
| 16 | Remove Foley catheter from wrap and lubricate catheter |
| 17.1 | Use the nondominant hand for the genitalia and the dominant hand for the swabs. |
| 17.2 | Use each swab stick for one swipe only |
| 17 F | Female Patient - Prepare patient with 3 foam swab sticks saturated in Povidone Iodine, then:<br>1. With a downward stroke cleanse the right labia minora<br>2. Discard the swab.<br>3. Do the same (repeat step 1) for the left labia minora.<br>4. Discard the swab.<br>5. With the last swabstick, cleanse the middle area between the labia minora |
| 17 M | Male Patient - Prepare patient with 3 foam swab sticks saturated in Povidone Iodine, then:<br>1. Cleanse the penis in a circular motion starting at the urethral meatus and working outward |
| 18 | Proceed with catheterization in usual manner using the dominant hand:<br>4. When catheter tip has entered bladder, urine will be visible in the drainage tube<br>5. Insert catheter two more inches<br>6. Inflate catheter balloon |

| | |
|---|---|
| 19 | Inflate catheter balloon using entire 10cc of sterile water provided in prefilled syringe |
| 20 | Once inflated, gently pull catheter until the inflated balloon is snug against the bladder neck |
| 21 | Secure the Foley catheter to the patient (Use the STATLOCK Foley Stabilization Device if provided) |
| 21.1 | Make sure patient is appropriate for use of STATLOCK Stabilization Device |
| 22 | Position hanger on bed rail at the foot of the bed |
| 22.1 | Exercise care to keep the bag off the floor |
| 23 | Use green sheeting clip to secure drainage tube to the sheet |
| 24 | Make sure tube is not kinked |
| 25 | Indicate time and date of insertion on provided labels |
| 26 | Place designated labels on patient chart and drainage system |
| 27 | Document procedure according to hospital protocol |
| OBS | Obese patient requires 2+ nurses |

# Appendix B - Questionnaire Response Data

Table B-1: Questionnaire Responses - Assessed Proportion of Affect

| | | Response | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Director Nursing Education Program** | **Infection Control Manager RN** | **Nurse Manager** | **Nursing Supervisor** | **Nursing Faculty** | **Nurse Supervisor, Emergency Department** | **Infection Prevention Supervisor** | **RN** |
| **Step** | **EPC** | 27+ yrs | 28 yrs | 31 yrs, 2 mo | 7.5 yrs | 25+ yrs | 37 yrs | 15+ yrs | 32 yrs |
| 1 | 1 | 4 | 8 | 10 | 3 | 5 | 9.1 | 8.1 | 9 |
| 1 | 15 | 8.1 | 6.1 | 5 | 5 | 5 | 9.2 | 9.1 | 5 |
| 1 | 16 | 8 | 8 | 8 | 7 | 5 | 5.1 | 6 | 4 |
| 1 | 18 | 5 | 8.7 | 10 | 3 | 5 | 5 | 9.4 | 6 |
| 1 | A | 4.1 | 9.2 | 10 | 8 | 5 | 8.1 | 4 | 3 |
| 1 | B | 9.1 | 9 | 10 | 8 | 4 | 5.1 | 8.3 | 5 |
| 1.1 | 1 | 5 | 3.6 | 8.1 | 2 | 5 | 6.2 | 5.1 | 7 |
| 1.1 | 15 | 9.1 | 8.1 | 10 | 3 | 5 | 8.1 | 7 | 6 |
| 1.1 | 16 | 5 | 8.4 | 10 | 8.5 | 5 | 6.1 | 7.1 | 6 |
| 1.1 | 18 | 5 | 9 | 5 | 1* | 5 | 5.2 | 7.1 | 5 |
| 1.1 | A | 5 | 9.1 | 10 | 6 | 5 | 8.2 | 4.1 | 4 |
| 1.1 | B | 9.2 | 9.1 | 3.9 | 9 | 5 | 6.1 | 6.9 | 5 |
| 2 | 1 | 8.1 | 4.4 | 5 | 0 | 0.1 | 1.9 | 4.5 | 4 |
| 2 | 15 | 9.1 | 7.1 | 5 | 0 | 0.1 | 1.9 | 4.6 | 4 |
| 2 | A | 5 | 9.1 | 4.9 | 0 | 0.1 | 5.1 | 3 | 5 |
| 2 | B | 9.1 | 9.1 | 2.5 | 0 | 0.1 | 5.2 | 5.1 | 6 |
| 3 | 1 | 8.1 | 8.2 | 10 | 7.5 | 10 | 10 | 9.5 | 10 |
| 3 | 12 | 9.1 | 8.4 | 10 | 5* | 8 | 10 | 9.4 | 9 |
| 3 | 15 | 9.1 | 9.2 | 10 | 7 | 8.5 | 10 | 9 | 9 |
| 3 | 18 | 5 | 4.9 | 5 | 2 | 9 | 8.1 | 9.5 | 8 |
| 3 | 21 | 10 | 5.7 | 5.1 | 1 | 10 | 5.1 | 7.1 | 9 |
| 3 | A | 6.1 | 9.7 | 5 | 6 | 10 | 8.2 | 7.3 | 4 |
| 3 | B | 9.2 | 9.8 | 7 | 8.5 | 10 | 8 | 9.6 | 8 |
| 4 | 1 | 7.1 | 8.7 | 10 | 3* | 10 | 8.2 | 8.4 | 8 |
| 4 | 4 | 7.1 | 8.7 | 5.2 | 1 | 10 | 8.2 | 8.4 | 6 |
| 4 | 15 | 9.2 | 9.1 | 7.4 | 4 | 10 | 5.1 | 5.5 | 9 |
| 4 | A | 7.1 | 9 | 5.1 | 4 | 10 | 8.8 | 4 | 6 |
| 4 | B | 9.2 | 9.2 | 7.5 | 7 | 10 | 7.5 | 7.9 | 5 |
| 5 | 1 | 6 | 3.6 | 10 | 4 | 9 | 8.2 | 3.5 | 8 |
| 5 | 2 | 8.1 | 9.3 | 10 | 4 | 9.2 | 9 | 4.9 | 8 |
| 5 | 9 | 9.1 | 4 | 2.8 | 0 | 6 | 7.4 | 9.7 | 8 |
| 5 | 12 | 10 | 5.2 | 10 | 6 | 9 | 8.4 | 9.6 | 7 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 15 | 10 | 7.2 | 7.5 | 9 | 10 | 8.7 | 5 | 8.1 |
| 5 | 18 | 5.1 | 4 | 2 | 2 | 9 | 6.4 | 9.4 | 5 |
| 5 | A | 6.1 | 9.1 | 4.9 | 4 | 10 | 9.3 | 3.8 | 4 |
| 5 | B | 9.1 | 9.3 | 8.1 | 9 | 10 | 6.6 | 9.5 | 6 |
| 6 | 1 | 7.1 | 8.1 | 6.1 | 3 | 10 | 10 | 6.5 | 9 |
| 6 | 12 | 10 | 8.4 | 8.3 | 6 | 9 | 10 | 9.3 | 8 |
| 6 | 15 | 10 | 8.4 | 7 | 7 | 9 | 8.4 | 6.9 | 8 |
| 6 | 18 | 6 | 4.7 | 2.1 | 1 | 9 | 7.3 | 9.4 | 8 |
| 6 | 21 | 10 | 7.6 | 5 | 0 | 9 | 5.1 | 9.5 | 8 |
| 6 | A | 9.1 | 9 | 4.9 | 3 | 8.1 | 9.8 | 4.1 | 8 |
| 6 | B | 9 | 9.1 | 8.1 | 5* | 8.1 | 8.8 | 9.3 | 8 |
| 7 | 1 | 7 | 9.4 | 4.9 | 1 | 2 | 5.1 | 9 | 7 |
| 7 | 2 | 9.1 | 8.8 | 10 | 5 | 0.2 | 5.4 | 6 | 6 |
| 7 | 4 | 6.1 | 8.5 | 5 | 1 | 0.1 | 8.5 | 7.7 | 6 |
| 7 | 15 | 8.1 | 8.9 | 5.1 | 5 | 0.1* | 5.3 | 7.6 | 7 |
| 7 | 18 | 7.1 | 8.7 | 1.9 | 3 | 0.1 | 5.1 | 8.5 | 6 |
| 7 | A | 4 | 8.8 | 5.1 | 5 | 0.1 | 9 | 3 | 4 |
| 7 | B | 8.2 | 9 | 3.5 | 6 | 0.1 | 4.9 | 9.3 | 5 |
| 8 | 1 | 5 | 5.1 | 5 | 2 | 2 | 5.1 | 3.1 | 6 |
| 8 | 4 | 6.1 | 5.3 | 5.1 | 1 | 2 | 5 | 7.7 | 6 |
| 8 | 15 | 8.2 | 7.4 | 5 | 5 | 8 | 5.1 | 7.8 | 6 |
| 8 | 18 | 5 | 3.5 | 1.9 | 3 | 0.1 | 5.1 | 9.5* | 5 |
| 8 | A | 6 | 8.1 | 5 | 4 | 0.1 | 5 | 2.6 | 4 |
| 8 | B | 8.1 | 8.4 | 2 | 5 | 0.1 | 5.1 | 9.6 | 6.1 |
| 9 | 1 | 5 | 6.4 | 8.1 | 5 | 0.1 | 8.4 | 6.1 | 4 |
| 9 | 9 | 5 | 6.8 | 1.8 | 0 | 0.1 | 7.2 | 9.1 | 5 |
| 9 | 12 | 6 | 8.3 | 4.9 | 4 | 0.1 | 7.1 | 9.2 | 5 |
| 9 | 15 | 6 | 8.9 | 2 | 6 | 0.1 | 7.1 | 6 | 4 |
| 9 | 16 | 5 | 3.6 | 10 | 4 | 0.1 | 5.1 | 9.3 | 4 |
| 9 | 21 | 5 | 7.3 | 10 | 0 | 0.1 | 5.1 | 9.2 | 6 |
| 9 | A | 5 | 9.3 | 2.9 | 7 | 0.1 | 9.1 | 4 | 3 |
| 9 | B | 5 | 9.2 | 5.4 | 7 | 0.1 | 4.2 | 9.5 | 6 |
| 10 | 1 | 6 | 9.8 | 3 | 7 | 8.9 | 10 | 3.9 | 8 |
| 10 | 7 | 6 | 9.8 | 10 | 2.5 | 10 | 10 | 7.5 | 9.1 |
| 10 | 15 | 7 | 8.2 | 10 | 6 | 9.3 | 8.1 | 8.9 | 9 |
| 10 | A | 6 | 9.3 | 2.4 | 4 | 4.8 | 9.2 | 2.9 | 7 |
| 10 | B | 8.1 | 9.3 | 10 | 8 | 7.3 | 5.1 | 8.5 | 8 |
| 11 | 1 | 8 | 9.7 | 10 | 5 | 10 | 10 | 4.9 | 9 |
| 11 | 7 | 9.1 | 9.7 | 10 | 1 | 10 | 10 | 2.9 | 9 |
| 11 | 15 | 9.1 | 9.8 | 4.8 | 7 | 10 | 8.3 | 3.3 | 9 |
| 11 | A | 6 | 9.7 | 5 | 6 | 10 | 9 | 3.1 | 5 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 11 | B | 9 | 8.6 | 5.1 | 7 | 10 | 6.1 | 8.2 | 8 |
| 12 | 1 | 6 | 3.7 | 10 | 3 | 0.1 | 5 | 0.6 | 4 |
| 12 | 7 | 6 | 6.1 | 10 | 0 | 0.1 | 5.1 | 6.6 | 4 |
| 12 | 15 | 7 | 6.2 | 5 | 6 | 0.1 | 4 | 6.6 | 4 |
| 12 | 28 | 5 | 4.9 | 8.1 | 3 | 0.1 | 4.1 | 0.6 | 3 |
| 12 | A | 5 | 7.2 | 5.2 | 4 | 0.1* | 8.2 | 2.4 | 3 |
| 12 | B | 7 | 7.5 | 4.9 | 7 | 0.1 | 4 | 8.8 | 4 |
| 13 | 1 | 6 | 6.2 | 10 | 5 | 0.1 | 9.1 | 8.5 | 5 |
| 13 | 6 | 7 | 6.1 | 5 | 5 | 0.1* | 7.2 | 9.3 | 6 |
| 13 | 9 | 8 | 6.2 | 4.9 | 0 | 0.1 | 7 | 9.4 | 7 |
| 13 | 15 | 9.1 | 7.1 | 5 | 5 | 0.1 | 8 | 9.5 | 6 |
| 13 | A | 5 | 7.1 | 5.5 | 5 | 0.1 | 9.2 | 2.8 | 6 |
| 13 | B | 9.2 | 7.3 | 2 | 5 | 0.1 | 4.2 | 8.9 | 7 |
| 14 | 1 | 5 | 4.1 | 10 | 6 | 9.5 | 10 | 0.8 | 7 |
| 14 | 6 | 4.9 | 7 | 10 | 5 | 9.5 | 8.2 | 1 | 8 |
| 14 | 15 | 7.1 | 7.8 | 10 | 7 | 9.5 | 8.1 | 3.2* | 8 |
| 14 | A | 5 | 7.9 | 10 | 5 | 9.5 | 9.2 | 0.4 | 6 |
| 14 | B | 7.1 | 8.2 | 10 | 7 | 9.5 | 5.6 | 5 | 8.1 |
| 15 | 1 | 5 | 6.1 | 10* | 5 | 6 | 5.2 | 0.6* | 4 |
| 15 | 9 | 6 | 4.8 | 10 | 0 | 8.6 | 5.1 | 0.7 | 4 |
| 15 | 15 | 6 | 6.5 | 10 | 7 | 8.6 | 8.3 | 3.1 | 4 |
| 15 | 23 | 7.1 | 5.9 | 10 | 7 | 8.6 | 7.2 | 1.2 | 5 |
| 15 | A | 5 | 6 | 2 | 6 | 8.6 | 8.8 | 2.5 | 4 |
| 15 | B | 6.1 | 6.2 | 1.9 | 7 | 8.6 | 5 | 1.5 | 6 |
| 16 | 1 | 7.1 | 8.2 | 10 | 5 | 10 | 8 | 5 | 8 |
| 16 | 11 | 8.1 | 7.7 | 10 | 7 | 10 | 8.1 | 5.1 | 8 |
| 16 | 15 | 10 | 8.1 | 10 | 8 | 10 | 8.2 | 5.1 | 9 |
| 16 | A | 6.1 | 8 | 6 | 6 | 10 | 9.2 | 1.9 | 5 |
| 16 | B | 10 | 7.9 | 7.1 | 7 | 10 | 6.1 | 7.4 | 9 |
| 17F | 1 | 7 | 8.6 | 10 | 5 | 10 | 10 | 2 | 10 |
| 17F | 2 | 9.2 | 9.7 | 8.1 | 7 | 10 | 7.2 | 4.9 | 9 |
| 17F | 12 | 10 | 9.7 | 10 | 6 | 10 | 8.2 | 3.4 | 10 |
| 17F | 15 | 10 | 8.7 | 10 | 8 | 10 | 8.2 | 3.5* | 10 |
| 17F | 17 | 8 | 3 | 10 | 0 | 10 | 8.2 | 0.5 | 9 |
| 17F | A | 6 | 8.3 | 5 | 5 | 10 | 9.3 | 2 | 7 |
| 17F | B | 9.1 | 8.4 | 5 | 8 | 10 | 7.1 | 5 | 8 |
| 17A | 1 | 5 | 3.9 | 10 | 4 | 7.6 | 8.1 | 0.9 | 7 |
| 17A | 2 | 5 | 5.8 | 10 | 4 | 6.6 | 8.1 | 1.3 | 7 |
| 17A | 12 | 7 | 6.3 | 5 | 0 | 7 | 6.2 | 1.2 | 7 |
| 17A | 15 | 7 | 7.3 | 10 | 4 | 9.1 | 8.1 | 4 | 8 |
| 17A | 21 | 8 | 8.9 | 5 | 0 | 7 | 7.2 | 0.9 | 8 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 17A | A | 5 | 6.6 | 5 | 5 | 7 | 9.2 | 1.4* | 6 |
| 17A | B | 5 | 6.6 | 5 | 6 | 7 | 5 | 1.2* | 8 |
| 17B | 1 | 5 | 7.6 | 10 | 7.5 | 10 | 10 | 0.8 | 9 |
| 17B | 15 | 6 | 8.2 | 4.9 | 7.5 | 10 | 9 | 4.1 | 9 |
| 17B | A | 4.1 | 6.9 | 5 | 5 | 10 | 9.2 | 0.9 | 7 |
| 17B | B | 4 | 7.1 | 7.5 | 6 | 10 | 7.1 | 2.7 | 8 |
| 17M | 1 | 5 | 7.5 | 10 | 5 | 10 | 10 | 1.2 | 9 |
| 17M | 2 | 4 | 9.8 | 10 | 3 | 10 | 9.1 | 1.3 | 9 |
| 17M | 12 | 6 | 9.4 | 7.5 | 5 | 10 | 9 | 1.2 | 9 |
| 17M | 15 | 6.1 | 8.3 | 10 | 7 | 10 | 8 | 5 | 9 |
| 17M | 21 | 6 | 8.6 | 6 | 0 | 10 | 6.1 | 0.7 | 10 |
| 17M | A | 4 | 8.1 | 5 | 4 | 10 | 9 | 0.7 | 7 |
| 17M | B | 5 | 8.1 | 10 | 6 | 10 | 4.9 | 3 | 8 |
| 18 | 1 | 7 | 9.2 | 10 | 6 | 8.1 | 10 | 2.5 | 9 |
| 18 | 2 | 5 | 4.7 | 10 | 1 | 8 | 7.2 | 0.9 | 9 |
| 18 | 4 | 6 | 4.2 | 5 | 0 | 9.1 | 7.3 | 1.5 | 7 |
| 18 | 7 | 7.1 | 8.8 | 10 | 1 | 9.1 | 8.2 | 1.6 | 9 |
| 18 | 11 | 8.1 | 7 | 10 | 4.5 | 10 | 8.2 | 1.2 | 9 |
| 18 | 14 | 8 | 6.3 | 10 | 4 | 10 | 7.1 | 1.4 | 8 |
| 18 | 15 | 9.1 | 8.1 | 10 | 9 | 10 | 7.2 | 2.8* | 9 |
| 18 | A | 5 | 7.9 | 5 | 6 | 8 | 9.1 | 0.8 | 7 |
| 18 | B | 7 | 7.9 | 5 | 7 | 8 | 6.2 | 4.8 | 8 |
| 19 | 1 | 6 | 4.8 | 10 | 5 | 7 | 10 | 1 | 7 |
| 19 | 2 | 4 | 4.2 | 10 | 2 | 7 | 8 | 1.3 | 8 |
| 19 | 6 | 6 | 5.6 | 5 | 3 | 7 | 6.8 | 4.7 | 8 |
| 19 | 15 | 8.1 | 5.4 | 5 | 6.5 | 8.1 | 8.1 | 4.9 | 9 |
| 19 | A | 4 | 6.7 | 7.5 | 5 | 7 | 9.2 | 1 | 5 |
| 19 | B | 4 | 7.1 | 10 | 5 | 7 | 6.1 | 1.7 | 8 |
| 20 | 1 | 4 | 4.4 | 9 | 5 | 0.1 | 10 | 2.5 | 5 |
| 20 | 4 | 4 | 5.1 | 5 | 0 | 2.9 | 8.1 | 1.3 | 3 |
| 20 | 13 | 4 | 3.9 | 5 | 4 | 3 | 8.1* | 2.3 | 4 |
| 20 | 14 | 4 | 4 | 4.9 | 4 | 2.9 | 5.2 | 1 | 4 |
| 20 | 15 | 5 | 6.4 | 7.5 | 7.5 | 2.9 | 6.2 | 5.1 | 4 |
| 20 | A | 3 | 6.4 | 5 | 4 | 2.9 | 8.2 | 0.8 | 3 |
| 20 | B | 4 | 6.7 | 5 | 4 | 2.9 | 5.1 | 2.9 | 6 |
| 21 | 1 | 2.9 | 7.6 | 10 | 8.5 | 9.1 | 7.1 | 2.7 | 4 |
| 21 | 4 | 2.9 | 7.7 | 4.9 | 0 | 9.1 | 7.1 | 2.3 | 4 |
| 21 | 9 | 3.9 | 7.5 | 6 | 0.5 | 9.1 | 6.9 | 2.4 | 5 |
| 21 | 15 | 4 | 7.5 | 6.2 | 7 | 9.1 | 8.2 | 2.4 | 4 |
| 21 | A | 3 | 8.5 | 5 | 4 | 9.1 | 8.2 | 1.4 | 3 |
| 21 | B | 2.9 | 8.4 | 10 | 6.5 | 9.1 | 5.2 | 2.6 | 6 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 21.1 | 1 | 5 | 6 | 10 | 4 | 7.6 | 3 | 1.8 | 3 |
| 21.1 | 15 | 5.1 | 6.1 | 10 | 6 | 7.6 | 2.9 | 1.8 | 3 |
| 21.1 | A | 3 | 6.2 | 2.1 | 5 | 7.7 | 5.1 | 1.3 | 2 |
| 21.1 | B | 4 | 6.2 | 5.5 | 4 | 7.5 | 3 | 2.1 | 3 |
| 22 | 1 | 5 | 6.5 | 10 | 5 | 0.1 | 5 | 1.4 | 4 |
| 22 | 4 | 5 | 5.8 | 1.9 | 0 | 0.1 | 5.1 | 1.5 | 4 |
| 22 | 6 | 5 | 8.4 | 5.1 | 1 | 0.1 | 6 | 1.4 | 3 |
| 22 | 9 | 5 | 8.1 | 10 | 0 | 0.1 | 4 | 1.5 | 4 |
| 22 | 12 | 7.1 | 8.6 | 10 | 4 | 0.1 | 5.2 | 5.1 | 4 |
| 22 | 15 | 7 | 7.9 | 10 | 7 | 0.1 | 5.1 | 5.1 | 4 |
| 22 | A | 4 | 6.8 | 5 | 5 | 0.1 | 7.2 | 1.3 | 3 |
| 22 | B | 4 | 7.9 | 5 | 5 | 0.1 | 2.9 | 5 | 3 |
| 22.1 | 1 | 6 | 3.6 | 5 | 3 | 4.1 | 5 | 5 | 4 |
| 22.1 | 15 | 7 | 3.9 | 6 | 5 | 4.1 | 5.2 | 5.3 | 4 |
| 22.1 | A | 3 | 6.3 | 5.5 | 2 | 4 | 8.2 | 1.5 | 2 |
| 22.1 | B | 4 | 5.6 | 10* | 4 | 4 | 5.1 | 5.1 | 4 |
| 23 | 1 | 3 | 6.1 | 7.5 | 4 | 3 | 3.9 | 4.9 | 2 |
| 23 | 4 | 2.9 | 6.6 | 5 | 0 | 3 | 4.1 | 9.6 | 1 |
| 23 | 6 | 3 | 7 | 1.9 | 1.5 | 3 | 5.1 | 9.6 | 3 |
| 23 | 9 | 3 | 6.8 | 6.5 | 0 | 3 | 3.1 | 9.7 | 3 |
| 23 | 12 | 3 | 8 | 5 | 2.5 | 3 | 5 | 9.7 | 3 |
| 23 | 15 | 3 | 7 | 5 | 6 | 3 | 5.1 | 9 | 3 |
| 23 | 18 | 3 | 6 | 5 | 1 | 3 | 5.1 | 9.5 | 2 |
| 23 | A | 3 | 7.1 | 5 | 2.5 | 1.9 | 8.1 | 1.5 | 2 |
| 23 | B | 3 | 7.9 | 10 | 4.5 | 1.8 | 5 | 9.5 | 2 |
| 24 | 1 | 2.9 | 8 | 10 | 6 | 10 | 7.1 | 5.4 | 4 |
| 24 | 15 | 2.9 | 9.1 | 10 | 7.5 | 10 | 7.2 | 5 | 4 |
| 24 | 16 | 3 | 8.2 | 10 | 0 | 10 | 5.1 | 9.3 | 4 |
| 24 | 18 | 3 | 8 | 10 | 9 | 10 | 5.1 | 9.5 | 6 |
| 24 | A | 3 | 8.4 | 6 | 3 | 10 | 8.2 | 1.2 | 4 |
| 24 | B | 3 | 9 | 6 | 4.5 | 10 | 5.2 | 8.3 | 7 |
| 25 | 1 | 3 | 4.9 | 10 | 2 | 4 | 5 | 7 | 3 |
| 25 | 15 | 4 | 5.7 | 8.4 | 2 | 4.1 | 3.1 | 5.4 | 3 |
| 25 | 16 | 3 | 7 | 10 | 4 | 4 | 3 | 5.7 | 4 |
| 25 | A | 3 | 8 | 5 | 3 | 4 | 5 | 1.1 | 2 |
| 25 | B | 3 | 7.9 | 5 | 5 | 4 | 3 | 7.4 | 4 |
| 26 | 1 | 3 | 7 | 2.9 | 3 | 4 | 2.9 | 6.3 | 4 |
| 26 | 15 | 3 | 7.2 | 5 | 5 | 4 | 3 | 6.3 | 4 |
| 26 | 16 | 3 | 6.3 | 6.1 | 3.5 | 4 | 3 | 5.9 | 4 |
| 26 | A | 3 | 6.9 | 5 | 3 | 4 | 5.1 | 1.2 | 3 |
| 26 | B | 3 | 6.9 | 9 | 4 | 4.1 | 3 | 8 | 4 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 27 | 1 | 2.9 | 8.4 | 8 | 6 | 8.6 | 5 | 1 | 4 |
| 27 | 9 | 3 | 8.5 | 10 | 1 | 8.5 | 5.2 | 1.8 | 5 |
| 27 | 15 | 3 | 8.6 | 10 | 8 | 8.6 | 5 | 3.9 | 5 |
| 27 | 16 | 3 | 6.7 | 5 | 3 | 8.4 | 3 | 2 | 5 |
| 27 | A | 3 | 7.6 | 8 | 7 | 8.4 | 6.2 | 1.4 | 3 |
| 27 | B | 3 | 9.5 | 8.2 | 7 | 8.6 | 4.1 | 4.4 | 6 |
| OBS | 1 | 7 | 9.1 | 10 | 5 | 10 | 7.1 | 9.2 | 7 |
| OBS | 12 | 8.1 | 9.2 | 8 | 4 | 10 | 5.2 | 9.9 | 7 |
| OBS | 15 | 9.2 | 9.7 | 9 | 7 | 10 | 5.1 | 9.7 | 9 |
| OBS | 20 | 8 | 8.1 | 10 | 3 | 10 | 5.1 | 0.8 | 8 |
| OBS | 24 | 8.1 | 6 | 8 | 1 | 10 | 5.1 | 2.7 | 5 |
| OBS | 27 | 7.1 | 7.2 | 7.1 | 7.5 | 10 | 6.2 | 9.6 | 4 |
| OBS | A | 6 | 9.5 | 10 | 2 | 10 | 8.2 | 1.6 | 4 |
| OBS | B | 8 | 9.3 | 7 | 7 | 10 | 6.3 | 9.7 | 8 |

*Denotes outlier, removed from data before performing calculations

Table B-2: Questionnaire Responses - Step Weight

| | Response | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Director Nursing Education Program** | **Infection Control Manager RN** | **Nurse Manager** | **Nursing Supervisor** | **Nursing Faculty** | **Nurse Supervisor, Emergency Department** | **Infection Prevention Supervisor** | **RN** |
| **Step** | 27+ yrs | 28 yrs | 31 yrs, 2 mo | 7.5 yrs | 25+ yrs | 37 yrs | 15+ yrs | 32 yrs |
| 1 | 5 | 8.1 | 10 | 10 | 6 | 8 | 7 | 4 |
| 1.1 | 6 | 5 | 8.1 | 1.9 | 5 | 8 | 2.1 | 4 |
| 2 | 7 | 4 | 10 | 2 | 0.1 | 5 | 6.1 | 1 |
| 3 | 7 | 9.8 | 10 | 10 | 10 | 10 | 9.4 | 7.1 |
| 4 | 4 | 7.9 | 6 | 6.1 | 2.4 | 5.1 | 9.5 | 7 |
| 5 | 5 | 10 | 3.9 | 10 | 8.6 | 8.2 | 9.3 | 8 |
| 6 | 5 | 9.6 | 3.2 | 10 | 10 | 10 | 9.5 | 9 |
| 7 | 3 | 7.1 | 7.7 | 1 | 1.6 | 5.1 | 4.1 | 6.1 |
| 8 | 6.1 | 9 | ** | 8 | 1.8 | 5 | 8.7 | 5 |
| 9 | 3 | 4.4 | 5.9 | 1 | 1.7 | 6.1 | 3.5 | 2 |
| 10 | 7.1 | 10 | 8 | 10 | 10 | 10 | 9.1 | 9.1 |
| 11 | 7.1 | 10 | 10 | 10 | 10 | 10 | 9.4 | 10 |
| 12 | 7 | 6.1 | 7.5 | 3 | 1.3 | 5 | 8.8 | 4 |
| 13 | 7.1 | 7.1 | 10 | 4.1 | 1.3 | 5.1 | 7.9 | 1 |
| 14 | 6 | 9.9 | 10 | 10 | 10 | 10 | 8.6 | 8 |
| 15 | 7.1 | 10 | 10 | 10 | 8.8 | 7.1 | 8 | 2.9 |
| 16 | 9.1 | 7.1 | 10 | 10 | 10 | 10 | * | 7.1 |
| 17F | 9.1 | 9.8 | 10 | 10 | 10 | 10 | 9.9 | 10 |
| 17M | 9.1 | 9.7 | 10 | 10 | 10 | 10 | 10 | 10 |
| 17A | 8.1 | 7.8 | 10 | 7.1 | 4.6 | 10 | 6 | 9.1 |
| 17B | 9.1 | 9.2 | 7.6 | 10 | 10 | 10 | 8.8 | 10 |
| 18 | 10 | 8.5 | 7.6 | 10 | 10 | 10 | 5.9 | 8.2 |
| 19 | 9.1 | 9.1 | 10 | 10 | 9.2 | 8.2 | 5 | 8.2 |
| 20 | 7.1 | 8 | 9.1 | 9.2 | 3.5 | 8.2 | 5.2 | 8.1 |
| 21 | 6 | 8.2 | 9.8 | 10 | 9.5 | 5.2 | 9.2 | 3 |
| 21.1 | 6.1 | 7.9 | 9.8 | 7.1 | 5 | 5 | 8.4 | 2.9 |
| 22 | 6.1 | 7.3 | 6.2 | 8.1 | 4 | 5.1 | 7.5 | 5.1 |
| 22.1 | 7.1 | 7.9 | 10 | 10 | 5.1 | 5 | 9.5 | 7.1 |
| 23 | 5 | 5.6 | 8.2 | 6 | 2.4 | 5 | 9.1 | 5.1 |
| 24 | 6.1 | 9.3 | 10 | 10 | 10 | 7.2 | 9.7 | 7.1 |
| 25 | 6.1 | 6 | 8.1 | 8.7 | 3.5 | 5 | 5 | 7.1 |
| 26 | 6 | 8 | 7.3 | 8.7 | 3.6 | 5 | 4.9 | 7 |
| 27 | 6 | 7.4 | 10 | 10 | 6.1 | 5 | 8 | 8.2 |

*Denotes outlier, removed before performing calculations
**Data not available

Table B-3: APOA Average and Standard Deviation by Step and EPC

| Step | EPC | Average | Standard Deviation |
|---|---|---|---|
| 1 | 1 | 0.703 | 0.264 |
| 1 | 15 | 0.656 | 0.192 |
| 1 | 16 | 0.639 | 0.159 |
| 1 | 18 | 0.651 | 0.253 |
| 1 | A | 0.643 | 0.269 |
| 1 | B | 0.731 | 0.227 |
| 1.1 | 1 | 0.525 | 0.191 |
| 1.1 | 15 | 0.704 | 0.229 |
| 1.1 | 16 | 0.701 | 0.181 |
| 1.1 | 18 | 0.590 | 0.157 |
| 1.1 | A | 0.643 | 0.235 |
| 1.1 | B | 0.678 | 0.211 |
| 2 | 1 | 0.350 | 0.272 |
| 2 | 15 | 0.398 | 0.322 |
| 2 | A | 0.403 | 0.298 |
| 2 | B | 0.464 | 0.356 |
| 3 | 1 | 0.916 | 0.105 |
| 3 | 12 | 0.913 | 0.075 |
| 3 | 15 | 0.898 | 0.095 |
| 3 | 18 | 0.644 | 0.260 |
| 3 | 21 | 0.663 | 0.307 |
| 3 | A | 0.704 | 0.216 |
| 3 | B | 0.876 | 0.106 |
| 4 | 1 | 0.863 | 0.106 |
| 4 | 4 | 0.683 | 0.281 |
| 4 | 15 | 0.741 | 0.226 |
| 4 | A | 0.675 | 0.234 |
| 4 | B | 0.791 | 0.157 |
| 5 | 1 | 0.654 | 0.261 |
| 5 | 2 | 0.781 | 0.219 |
| 5 | 9 | 0.588 | 0.337 |
| 5 | 12 | 0.815 | 0.187 |
| 5 | 15 | 0.819 | 0.165 |
| 5 | 18 | 0.536 | 0.281 |
| 5 | A | 0.640 | 0.265 |
| 5 | B | 0.845 | 0.144 |
| 6 | 1 | 0.748 | 0.234 |
| 6 | 12 | 0.863 | 0.130 |
| 6 | 15 | 0.809 | 0.110 |

| | | | |
|---|---|---|---|
| 6 | 18 | 0.594 | 0.312 |
| 6 | 21 | 0.678 | 0.331 |
| 6 | A | 0.700 | 0.260 |
| 6 | B | 0.863 | 0.055 |
| 7 | 1 | 0.568 | 0.304 |
| 7 | 2 | 0.631 | 0.311 |
| 7 | 4 | 0.536 | 0.323 |
| 7 | 15 | 0.671 | 0.159 |
| 7 | 18 | 0.505 | 0.314 |
| 7 | A | 0.488 | 0.294 |
| 7 | B | 0.575 | 0.311 |
| 8 | 1 | 0.416 | 0.156 |
| 8 | 4 | 0.478 | 0.221 |
| 8 | 15 | 0.656 | 0.143 |
| 8 | 18 | 0.337 | 0.188 |
| 8 | A | 0.435 | 0.236 |
| 8 | B | 0.555 | 0.325 |
| 9 | 1 | 0.539 | 0.262 |
| 9 | 9 | 0.438 | 0.340 |
| 9 | 12 | 0.558 | 0.284 |
| 9 | 15 | 0.501 | 0.284 |
| 9 | 16 | 0.514 | 0.319 |
| 9 | 21 | 0.534 | 0.372 |
| 9 | A | 0.505 | 0.322 |
| 9 | B | 0.580 | 0.299 |
| 10 | 1 | 0.708 | 0.262 |
| 10 | 7 | 0.811 | 0.270 |
| 10 | 15 | 0.831 | 0.130 |
| 10 | A | 0.570 | 0.266 |
| 10 | B | 0.804 | 0.146 |
| 11 | 1 | 0.833 | 0.219 |
| 11 | 7 | 0.771 | 0.361 |
| 11 | 15 | 0.766 | 0.245 |
| 11 | A | 0.673 | 0.253 |
| 11 | B | 0.775 | 0.160 |
| 12 | 1 | 0.405 | 0.314 |
| 12 | 7 | 0.474 | 0.336 |
| 12 | 15 | 0.554 | 0.122 |
| 12 | 28 | 0.360 | 0.257 |
| 12 | A | 0.439 | 0.262 |
| 12 | B | 0.541 | 0.276 |

| | | | |
|---|---|---|---|
| 13 | 1 | 0.624 | 0.312 |
| 13 | 6 | 0.651 | 0.150 |
| 13 | 9 | 0.533 | 0.350 |
| 13 | 15 | 0.623 | 0.301 |
| 13 | A | 0.509 | 0.273 |
| 13 | B | 0.546 | 0.325 |
| 14 | 1 | 0.655 | 0.326 |
| 14 | 6 | 0.670 | 0.296 |
| 14 | 15 | 0.821 | 0.114 |
| 14 | A | 0.663 | 0.321 |
| 14 | B | 0.756 | 0.175 |
| 15 | 1 | 0.522 | 0.077 |
| 15 | 9 | 0.490 | 0.345 |
| 15 | 15 | 0.669 | 0.233 |
| 15 | 23 | 0.650 | 0.263 |
| 15 | A | 0.536 | 0.252 |
| 15 | B | 0.529 | 0.244 |
| 16 | 1 | 0.766 | 0.192 |
| 16 | 11 | 0.800 | 0.158 |
| 16 | 15 | 0.855 | 0.165 |
| 16 | A | 0.653 | 0.256 |
| 16 | B | 0.806 | 0.145 |
| 17F | 1 | 0.783 | 0.298 |
| 17F | 2 | 0.814 | 0.171 |
| 17F | 12 | 0.841 | 0.247 |
| 17F | 15 | 0.927 | 0.093 |
| 17F | 17 | 0.609 | 0.423 |
| 17F | A | 0.658 | 0.263 |
| 17F | B | 0.758 | 0.180 |
| 17A | 1 | 0.581 | 0.291 |
| 17A | 2 | 0.598 | 0.264 |
| 17A | 12 | 0.496 | 0.279 |
| 17A | 15 | 0.719 | 0.219 |
| 17A | 21 | 0.563 | 0.340 |
| 17A | A | 0.626 | 0.153 |
| 17A | B | 0.609 | 0.118 |
| 17B | 1 | 0.749 | 0.321 |
| 17B | 15 | 0.734 | 0.212 |
| 17B | A | 0.601 | 0.292 |
| 17B | B | 0.655 | 0.230 |
| 17M | 1 | 0.721 | 0.322 |

| | | | |
|---|---|---|---|
| 17M | 2 | 0.703 | 0.362 |
| 17M | 12 | 0.714 | 0.296 |
| 17M | 15 | 0.793 | 0.180 |
| 17M | 21 | 0.593 | 0.383 |
| 17M | A | 0.598 | 0.311 |
| 17M | B | 0.688 | 0.255 |
| 18 | 1 | 0.773 | 0.254 |
| 18 | 2 | 0.573 | 0.345 |
| 18 | 4 | 0.501 | 0.305 |
| 18 | 7 | 0.685 | 0.353 |
| 18 | 11 | 0.725 | 0.302 |
| 18 | 14 | 0.685 | 0.294 |
| 18 | 15 | 0.891 | 0.100 |
| 18 | A | 0.610 | 0.260 |
| 18 | B | 0.674 | 0.129 |
| 19 | 1 | 0.635 | 0.294 |
| 19 | 2 | 0.556 | 0.314 |
| 19 | 6 | 0.576 | 0.156 |
| 19 | 15 | 0.689 | 0.164 |
| 19 | A | 0.568 | 0.251 |
| 19 | B | 0.611 | 0.255 |
| 20 | 1 | 0.500 | 0.322 |
| 20 | 4 | 0.368 | 0.250 |
| 20 | 13 | 0.374 | 0.086 |
| 20 | 14 | 0.375 | 0.131 |
| 20 | 15 | 0.558 | 0.163 |
| 20 | A | 0.416 | 0.232 |
| 20 | B | 0.458 | 0.138 |
| 21 | 1 | 0.649 | 0.288 |
| 21 | 4 | 0.475 | 0.306 |
| 21 | 9 | 0.516 | 0.282 |
| 21 | 15 | 0.605 | 0.235 |
| 21 | A | 0.528 | 0.294 |
| 21 | B | 0.634 | 0.274 |
| 21.1 | 1 | 0.505 | 0.273 |
| 21.1 | 15 | 0.531 | 0.272 |
| 21.1 | A | 0.405 | 0.229 |
| 21.1 | B | 0.441 | 0.184 |
| 22 | 1 | 0.463 | 0.303 |
| 22 | 4 | 0.293 | 0.233 |
| 22 | 6 | 0.375 | 0.285 |

| | | | |
|---|---|---|---|
| 22 | 9 | 0.409 | 0.361 |
| 22 | 12 | 0.551 | 0.308 |
| 22 | 15 | 0.578 | 0.297 |
| 22 | A | 0.405 | 0.249 |
| 22 | B | 0.411 | 0.225 |
| 22.1 | 1 | 0.446 | 0.096 |
| 22.1 | 15 | 0.506 | 0.108 |
| 22.1 | A | 0.406 | 0.240 |
| 22.1 | B | 0.454 | 0.070 |
| 23 | 1 | 0.430 | 0.180 |
| 23 | 4 | 0.403 | 0.308 |
| 23 | 6 | 0.426 | 0.279 |
| 23 | 9 | 0.439 | 0.305 |
| 23 | 12 | 0.490 | 0.265 |
| 23 | 15 | 0.514 | 0.217 |
| 23 | 18 | 0.433 | 0.269 |
| 23 | A | 0.389 | 0.254 |
| 23 | B | 0.546 | 0.328 |
| 24 | 1 | 0.668 | 0.261 |
| 24 | 15 | 0.696 | 0.274 |
| 24 | 16 | 0.620 | 0.373 |
| 24 | 18 | 0.758 | 0.260 |
| 24 | A | 0.548 | 0.315 |
| 24 | B | 0.663 | 0.239 |
| 25 | 1 | 0.486 | 0.259 |
| 25 | 15 | 0.446 | 0.201 |
| 25 | 16 | 0.509 | 0.240 |
| 25 | A | 0.389 | 0.215 |
| 25 | B | 0.491 | 0.186 |
| 26 | 1 | 0.414 | 0.163 |
| 26 | 15 | 0.469 | 0.150 |
| 26 | 16 | 0.448 | 0.140 |
| 26 | A | 0.390 | 0.175 |
| 26 | B | 0.525 | 0.236 |
| 27 | 1 | 0.549 | 0.278 |
| 27 | 9 | 0.538 | 0.335 |
| 27 | 15 | 0.651 | 0.259 |
| 27 | 16 | 0.451 | 0.219 |
| 27 | A | 0.558 | 0.270 |
| 27 | B | 0.635 | 0.236 |
| OBS | 1 | 0.805 | 0.179 |

| | | | |
|---|---|---|---|
| OBS | 12 | 0.768 | 0.217 |
| OBS | 15 | 0.859 | 0.168 |
| OBS | 20 | 0.663 | 0.334 |
| OBS | 24 | 0.574 | 0.297 |
| OBS | 27 | 0.734 | 0.188 |
| OBS | A | 0.641 | 0.353 |
| OBS | B | 0.816 | 0.138 |

Table B-4: Step Weight Average and Standard Deviation

| Step | Average | Standard Deviation |
|---|---|---|
| 1 | 0.726 | 0.219 |
| 1.1 | 0.501 | 0.235 |
| 2 | 0.440 | 0.332 |
| 3 | 0.916 | 0.132 |
| 4 | 0.600 | 0.222 |
| 5 | 0.788 | 0.226 |
| 6 | 0.829 | 0.265 |
| 7 | 0.446 | 0.248 |
| 8 | 0.623 | 0.257 |
| 9 | 0.345 | 0.190 |
| 10 | 0.916 | 0.110 |
| 11 | 0.991 | 0.023 |
| 12 | 0.534 | 0.250 |
| 13 | 0.545 | 0.319 |
| 14 | 0.906 | 0.146 |
| 15 | 0.799 | 0.240 |
| 16 | 0.904 | 0.137 |
| 17F | 0.996 | 0.008 |
| 17M | 0.996 | 0.011 |
| 17A | 0.784 | 0.191 |
| 17B | 0.934 | 0.086 |
| 18 | 0.878 | 0.151 |
| 19 | 0.911 | 0.074 |
| 20 | 0.730 | 0.199 |
| 21 | 0.761 | 0.258 |
| 21.1 | 0.653 | 0.222 |
| 22 | 0.618 | 0.140 |
| 22.1 | 0.771 | 0.202 |
| 23 | 0.580 | 0.207 |
| 24 | 0.868 | 0.160 |
| 25 | 0.619 | 0.173 |
| 26 | 0.631 | 0.174 |
| 27 | 0.759 | 0.184 |

# Appendix C - CAUTI Probabilities for Task Type E/H Model

Table C-1: CAUTI Probabilities for Task Type E/H Model

| | Patient Case | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gender** | **M** | **M** | **M** | **M** | **F(Best)** | **F(Best)** | **F(Best)** | **F(Best)** | **F(Worst)** | **F(Worst)** | **F(Worst)** | **F(Worst)** |
| **Diabetes** | No | No | Yes | Yes | No | No | Yes | Yes | No | No | Yes | Yes |
| **Obese** | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| **Day/P0** | 0.1272 | 0.1422 | 0.1272 | 0.1422 | 0.1297 | 0.1447 | 0.1297 | 0.1447 | 0.0704 | 0.1447 | 0.1297 | 0.1447 |
| 0 | 0.127 | 0.142 | 0.286 | 0.320 | 0.324 | 0.362 | 0.730 | 0.814 | 0.480 | 0.535 | 1.080 | 1.205 |
| 1 | 0.134 | 0.149 | 0.300 | 0.336 | 0.340 | 0.380 | 0.766 | 0.855 | 0.504 | 0.562 | 1.134 | 1.265 |
| 2 | 0.140 | 0.157 | 0.316 | 0.353 | 0.357 | 0.399 | 0.804 | 0.897 | 0.529 | 0.590 | 1.190 | 1.328 |
| 3 | 0.147 | 0.165 | 0.331 | 0.370 | 0.375 | 0.419 | 0.845 | 0.942 | 0.555 | 0.620 | 1.250 | 1.394 |
| 4 | 0.155 | 0.173 | 0.348 | 0.389 | 0.394 | 0.440 | 0.887 | 0.989 | 0.583 | 0.651 | 1.312 | 1.464 |
| 5 | 0.162 | 0.181 | 0.365 | 0.408 | 0.414 | 0.462 | 0.931 | 1.039 | 0.612 | 0.683 | 1.378 | 1.537 |
| 6 | 0.170 | 0.191 | 0.384 | 0.429 | 0.434 | 0.485 | 0.978 | 1.091 | 0.643 | 0.717 | 1.447 | 1.614 |
| 7 | 0.179 | 0.200 | 0.403 | 0.450 | 0.456 | 0.509 | 1.027 | 1.145 | 0.675 | 0.753 | 1.519 | 1.695 |
| 8 | 0.188 | 0.210 | 0.423 | 0.473 | 0.479 | 0.534 | 1.078 | 1.203 | 0.709 | 0.791 | 1.595 | 1.780 |
| 9 | 0.197 | 0.221 | 0.444 | 0.496 | 0.503 | 0.561 | 1.132 | 1.263 | 0.744 | 0.831 | 1.675 | 1.869 |
| 10 | 0.207 | 0.232 | 0.466 | 0.521 | 0.528 | 0.589 | 1.188 | 1.326 | 0.782 | 0.872 | 1.759 | 1.962 |
| 11 | 0.218 | 0.243 | 0.489 | 0.547 | 0.555 | 0.619 | 1.248 | 1.392 | 0.821 | 0.916 | 1.847 | 2.060 |
| 12 | 0.228 | 0.255 | 0.514 | 0.575 | 0.582 | 0.650 | 1.310 | 1.462 | 0.862 | 0.961 | 1.939 | 2.163 |
| 13 | 0.240 | 0.268 | 0.540 | 0.603 | 0.611 | 0.682 | 1.376 | 1.535 | 0.905 | 1.010 | 2.036 | 2.271 |
| 14 | 0.252 | 0.282 | 0.567 | 0.633 | 0.642 | 0.716 | 1.444 | 1.611 | 0.950 | 1.060 | 2.138 | 2.385 |
| 15 | 0.264 | 0.296 | 0.595 | 0.665 | 0.674 | 0.752 | 1.517 | 1.692 | 0.998 | 1.113 | 2.245 | 2.504 |
| 16 | 0.278 | 0.310 | 0.625 | 0.698 | 0.708 | 0.790 | 1.592 | 1.777 | 1.047 | 1.169 | 2.357 | 2.629 |
| 17 | 0.292 | 0.326 | 0.656 | 0.733 | 0.743 | 0.829 | 1.672 | 1.865 | 1.100 | 1.227 | 2.475 | 2.761 |
| 18 | 0.306 | 0.342 | 0.689 | 0.770 | 0.780 | 0.871 | 1.756 | 1.959 | 1.155 | 1.288 | 2.598 | 2.899 |
| 19 | 0.321 | 0.359 | 0.723 | 0.808 | 0.819 | 0.914 | 1.843 | 2.057 | 1.213 | 1.353 | 2.728 | 3.044 |
| 20 | 0.337 | 0.377 | 0.759 | 0.849 | 0.860 | 0.960 | 1.936 | 2.160 | 1.273 | 1.420 | 2.865 | 3.196 |
| 21 | 0.354 | 0.396 | 0.797 | 0.891 | 0.903 | 1.008 | 2.032 | 2.268 | 1.337 | 1.492 | 3.008 | 3.356 |
| 22 | 0.372 | 0.416 | 0.837 | 0.936 | 0.948 | 1.058 | 2.134 | 2.381 | 1.404 | 1.566 | 3.158 | 3.524 |
| 23 | 0.391 | 0.437 | 0.879 | 0.983 | 0.996 | 1.111 | 2.241 | 2.500 | 1.474 | 1.644 | 3.316 | 3.700 |
| 24 | 0.410 | 0.459 | 0.923 | 1.032 | 1.046 | 1.167 | 2.353 | 2.625 | 1.548 | 1.727 | 3.482 | 3.885 |
| 25 | 0.431 | 0.482 | 0.969 | 1.083 | 1.098 | 1.225 | 2.470 | 2.756 | 1.625 | 1.813 | 3.656 | 4.079 |
| 26 | 0.452 | 0.506 | 1.018 | 1.138 | 1.153 | 1.286 | 2.594 | 2.894 | 1.706 | 1.904 | 3.839 | 4.283 |
| 27 | 0.475 | 0.531 | 1.068 | 1.194 | 1.210 | 1.351 | 2.724 | 3.039 | 1.792 | 1.999 | 4.031 | 4.497 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | 0.499 | 0.557 | 1.122 | 1.254 | 1.271 | 1.418 | 2.860 | 3.191 | 1.881 | 2.099 | 4.233 | 4.722 |
| 29 | 0.524 | 0.585 | 1.178 | 1.317 | 1.335 | 1.489 | 3.003 | 3.350 | 1.975 | 2.204 | 4.444 | 4.958 |
| 30 | 0.550 | 0.615 | 1.237 | 1.383 | 1.401 | 1.563 | 3.153 | 3.518 | 2.074 | 2.314 | 4.666 | 5.206 |
| 31 | 0.577 | 0.645 | 1.299 | 1.452 | 1.471 | 1.642 | 3.311 | 3.694 | 2.178 | 2.430 | 4.900 | 5.466 |
| 32 | 0.606 | 0.678 | 1.364 | 1.524 | 1.545 | 1.724 | 3.476 | 3.878 | 2.287 | 2.551 | 5.145 | 5.740 |
| 33 | 0.636 | 0.711 | 1.432 | 1.601 | 1.622 | 1.810 | 3.650 | 4.072 | 2.401 | 2.679 | 5.402 | 6.027 |
| 34 | 0.668 | 0.747 | 1.503 | 1.681 | 1.703 | 1.900 | 3.832 | 4.276 | 2.521 | 2.812 | 5.672 | 6.328 |
| 35 | 0.702 | 0.784 | 1.579 | 1.765 | 1.788 | 1.995 | 4.024 | 4.490 | 2.647 | 2.953 | 5.956 | 6.644 |
| 36 | 0.737 | 0.824 | 1.657 | 1.853 | 1.878 | 2.095 | 4.225 | 4.714 | 2.779 | 3.101 | 6.253 | 6.977 |
| 37 | 0.773 | 0.865 | 1.740 | 1.946 | 1.972 | 2.200 | 4.436 | 4.950 | 2.918 | 3.256 | 6.566 | 7.326 |
| 38 | 0.812 | 0.908 | 1.827 | 2.043 | 2.070 | 2.310 | 4.658 | 5.197 | 3.064 | 3.419 | 6.894 | 7.692 |
| 39 | 0.853 | 0.953 | 1.919 | 2.145 | 2.174 | 2.425 | 4.891 | 5.457 | 3.217 | 3.590 | 7.239 | 8.076 |
| 40 | 0.895 | 1.001 | 2.015 | 2.252 | 2.283 | 2.547 | 5.136 | 5.730 | 3.378 | 3.769 | 7.601 | 8.480 |
| 41 | 0.940 | 1.051 | 2.115 | 2.365 | 2.397 | 2.674 | 5.393 | 6.016 | 3.547 | 3.957 | 7.981 | 8.904 |
| 42 | 0.987 | 1.104 | 2.221 | 2.483 | 2.517 | 2.808 | 5.662 | 6.317 | 3.724 | 4.155 | 8.380 | 9.349 |
| 43 | 1.037 | 1.159 | 2.332 | 2.607 | 2.642 | 2.948 | 5.945 | 6.633 | 3.911 | 4.363 | 8.799 | 9.817 |
| 44 | 1.088 | 1.217 | 2.449 | 2.738 | 2.774 | 3.095 | 6.243 | 6.965 | 4.106 | 4.581 | 9.239 | 10.308 |
| 45 | 1.143 | 1.278 | 2.571 | 2.875 | 2.913 | 3.250 | 6.555 | 7.313 | 4.312 | 4.810 | 9.701 | 10.823 |

# Appendix D - Table of $M_{\%}$ Values

Table D-1: $M_{\%}$ Values by EPC and Step

| | EPC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Step** | **1** | **2** | **4** | **6** | **7** | **9** | **11** | **12** | **13** | **14** | **15** |
| **1** | 1.292E-06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.985E-07 |
| **1.1** | 6.732E-07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.404E-07 |
| **2** | 3.996E-08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.086E-08 |
| **3** | 8.178E-06 | 0 | 0 | 0 | 0 | 0 | 0 | 6.400E-06 | 0 | 0 | 5.611E-06 |
| **4** | 2.178E-06 | 0 | 1.974E-06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.395E-06 |
| **5** | 7.632E-05 | 7.413E-05 | 0 | 0 | 0 | 6.238E-05 | 0 | 5.934E-05 | 0 | 0 | 5.191E-05 |
| **6** | 5.200E-06 | 0 | 0 | 0 | 0 | 0 | 0 | 4.064E-06 | 0 | 0 | 3.482E-06 |
| **7** | 7.218E-06 | 6.917E-06 | 6.498E-06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.593E-06 |
| **8** | 7.101E-07 | 0 | 6.472E-07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.635E-07 |
| **9** | 1.815E-06 | 0 | 0 | 0 | 0 | 1.390E-06 | 0 | 1.267E-06 | 0 | 0 | 1.014E-06 |
| **10** | 2.689E-06 | 0 | 0 | 0 | 2.488E-06 | 0 | 0 | 0 | 0 | 0 | 1.827E-06 |
| **11** | 3.463E-06 | 0 | 0 | 0 | 3.141E-06 | 0 | 0 | 0 | 0 | 0 | 2.253E-06 |
| **12** | 3.656E-07 | 0 | 0 | 0 | 3.243E-07 | 0 | 0 | 0 | 0 | 0 | 2.219E-07 |
| **13** | 2.804E-06 | 0 | 0 | 2.531E-06 | 0 | 2.243E-06 | 0 | 0 | 0 | 0 | 1.711E-06 |
| **14** | 2.258E-06 | 0 | 0 | 2.039E-06 | 0 | 0 | 0 | 0 | 0 | 0 | 1.537E-06 |
| **15** | 8.634E-07 | 0 | 0 | 0 | 0 | 6.866E-07 | 0 | 0 | 0 | 0 | 5.532E-07 |
| **16** | 2.036E-06 | 0 | 0 | 0 | 0 | 0 | 1.678E-06 | 0 | 0 | 0 | 1.389E-06 |
| **17F** | 3.997E-05 | 3.844E-05 | 0 | 0 | 0 | 0 | 0 | 3.091E-05 | 0 | 0 | 2.804E-05 |
| **17M** | 1.668E-05 | 1.587E-05 | 0 | 0 | 0 | 0 | 0 | 1.236E-05 | 0 | 0 | 1.112E-05 |
| **17A** | 6.604E-06 | 6.266E-06 | 0 | 0 | 0 | 0 | 0 | 4.375E-06 | 0 | 0 | 4.313E-06 |
| **17B** | 3.795E-07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.445E-07 |
| **18** | 9.882E-04 | 9.093E-04 | 8.549E-04 | 0 | 8.838E-04 | 0 | 7.942E-04 | 0 | 0 | 7.185E-04 | 6.843E-04 |
| **19** | 9.296E-06 | 8.655E-06 | 0 | 8.183E-06 | 0 | 0 | 0 | 0 | 0 | 0 | 5.916E-06 |
| **20** | 2.017E-06 | 0 | 1.694E-06 | 0 | 0 | 0 | 0 | 0 | 1.201E-06 | 1.202E-06 | 1.197E-06 |
| **21** | 3.700E-06 | 0 | 3.211E-06 | 0 | 0 | 2.924E-06 | 0 | 0 | 0 | 0 | 2.221E-06 |
| **21.1** | 9.688E-08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.609E-08 |
| **22** | 8.372E-06 | 0 | 6.658E-06 | 6.881E-06 | 0 | 6.381E-06 | 0 | 5.922E-06 | 0 | 0 | 5.093E-06 |
| **22.1** | 9.998E-08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.735E-08 |
| **23** | 1.665E-05 | 0 | 1.456E-05 | 1.429E-05 | 0 | 1.310E-05 | 0 | 1.135E-05 | 0 | 0 | 9.667E-06 |
| **24** | 1.369E-06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.717E-07 |
| **25** | 1.659E-07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.831E-08 |
| **26** | 1.425E-07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.934E-08 |
| **27** | 1.381E-06 | 0 | 0 | 0 | 0 | 1.121E-06 | 0 | 0 | 0 | 0 | 8.702E-07 |
| **OBS** | 1.392E-04 | 0 | 0 | 0 | 0 | 0 | 0 | 1.046E-04 | 0 | 0 | 9.482E-05 |
| **SUM** | 1.060E-03 | 8.902E-04 | 3.392E-05 | 8.898E-04 | 9.023E-05 | 7.959E-04 | 2.406E-04 | 1.201E-06 | 7.197E-04 | 9.282E-04 | 1.060E-03 |

| | EPC | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Step** | **16** | **17** | **18** | **20** | **21** | **23** | **24** | **27** | **28** | **A** | **B** |
| **1** | 7.891E-07 | 0 | 6.952E-07 | 0 | 0 | 0 | 0 | 0 | 0 | 1.051E-06 | 6.746E-07 |
| **1.1** | 4.398E-07 | 0 | 3.537E-07 | 0 | 0 | 0 | 0 | 0 | 0 | 5.629E-07 | 3.469E-07 |
| **2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.058E-08 | 1.737E-08 |
| **3** | 0 | 0 | 4.292E-06 | 0 | 3.481E-06 | 0 | 0 | 0 | 0 | 6.675E-06 | 4.584E-06 |
| **4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.767E-06 | 1.166E-06 |
| **5** | 0 | 0 | 3.728E-05 | 0 | 0 | 0 | 0 | 0 | 0 | 6.241E-05 | 4.312E-05 |
| **6** | 0 | 0 | 2.654E-06 | 0 | 2.276E-06 | 0 | 0 | 0 | 0 | 4.300E-06 | 2.935E-06 |
| **7** | 0 | 0 | 3.454E-06 | 0 | 0 | 0 | 0 | 0 | 0 | 5.541E-06 | 3.366E-06 |
| **8** | 0 | 0 | 2.743E-07 | 0 | 0 | 0 | 0 | 0 | 0 | 5.445E-07 | 3.361E-07 |
| **9** | 1.026E-06 | 0 | 0 | 0 | 7.048E-07 | 0 | 0 | 0 | 0 | 1.416E-06 | 8.551E-07 |
| **10** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.119E-06 | 1.473E-06 |
| **11** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.813E-06 | 1.839E-06 |
| **12** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.313E-08 | 2.822E-07 | 1.711E-07 |
| **13** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.162E-06 | 1.258E-06 |
| **14** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.862E-06 | 1.207E-06 |
| **15** | 0 | 0 | 0 | 0 | 0 | 2.713E-07 | 0 | 0 | 0 | 6.879E-07 | 3.866E-07 |
| **16** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.652E-06 | 1.110E-06 |
| **17F** | 0 | 2.370E-05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.243E-05 | 2.108E-05 |
| **17M** | 0 | 0 | 0 | 0 | 6.745E-06 | 0 | 0 | 0 | 0 | 1.329E-05 | 8.415E-06 |
| **17A** | 0 | 0 | 0 | 0 | 2.633E-06 | 0 | 0 | 0 | 0 | 5.428E-06 | 3.174E-06 |
| **17B** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.020E-07 | 1.859E-07 |
| **18** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.875E-04 | 4.904E-04 |
| **19** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.383E-06 | 4.443E-06 |
| **20** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.491E-06 | 8.299E-07 |
| **21** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.873E-06 | 1.801E-06 |
| **21.1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.084E-08 | 3.890E-08 |
| **22** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.184E-06 | 3.244E-06 |
| **22.1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.425E-08 | 4.149E-08 |
| **23** | 0 | 0 | 7.506E-06 | 0 | 0 | 0 | 0 | 0 | 0 | 1.223E-05 | 7.777E-06 |
| **24** | 8.291E-07 | 0 | 7.966E-07 | 0 | 0 | 0 | 0 | 0 | 0 | 1.072E-06 | 6.814E-07 |
| **25** | 9.445E-08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.201E-07 | 7.160E-08 |
| **26** | 7.744E-08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.053E-07 | 6.528E-08 |
| **27** | 7.297E-07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.107E-06 | 6.837E-07 |
| **OBS** | 0 | 0 | 0 | 5.978E-05 | 0 | 0 | 3.84E-05 | 3.4E-05 | 0 | 1.120E-04 | 7.606E-05 |
| SUM | 3.986E-06 | 2.370E-05 | 5.730E-05 | 5.978E-05 | 1.584E-05 | 2.713E-07 | 3.842E-05 | 3.404E-05 | 5.313E-08 | 1.080E-03 | 6.839E-04 |

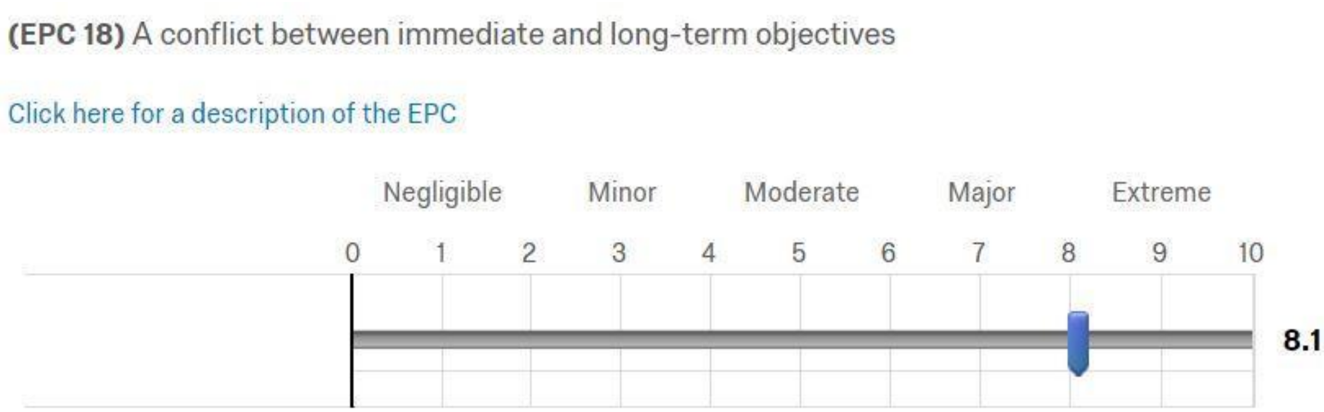
# Appendix E - Questionnaire Instructions

This survey will take approximately **60 minutes** to complete. You may save the survey at any point by closing your browser, and continue the survey later by re-opening the survey link.

<u>Purpose:</u> The purpose of this survey is to gather information regarding how various factors may affect the likelihood of an error in the urinary catheter insertion process, which could then lead to a catheter associated urinary tract infection (CAUTI).

<u>Instructions:</u> Each page will present a step in the urinary catheter insertion process (based on the BARD SureStep Foley Tray System) and a series of Error Producing Conditions (EPCs) that could contribute to an error leading to a CAUTI. A link to a description of each EPC is provided for each question. **Using the scale provided, please rate, on average, how significant each EPC is on the probability of committing an error while performing that step.** The higher the number selected, the greater the significance is of the EPC to potentially cause an error. (Note: If an EPC is has no effect on the probability of an error for a step, or is irrelevant, please select '0' on the scale.)

<u>Example:</u> Below is an example for the step "Wash hands and don clean gloves", where the assessor must evaluate the significance of "a conflict between immediate and long-term objectives":




In this example, the assessor has selected 8.1, meaning the EPC, "a conflict between immediate and long-term objectives", has moderately major significance on the probability of an error during the step "wash hands and don clean gloves".

For the purpose of this research, please do not collaborate with others when completing this survey. If you have any questions please contact Courtney Faucett at **cfaucett@ksu.edu** or **785-341-8528**.This survey is **<u>anonymous</u>** so please give your honest assessment of the factors presented.

Thank you for your time and expertise!